Trees and Air:
Local Action on Global Problems

Prepared for
The Honorable Vernon J. Ehlers
State Senator

FINAL REPORT
March 1990

Vernon J. Ehlers

State Senator • 32nd District • Kent County

The Senate
State of Michigan

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March 1990

Dear Friends:

Recently trees and forests have received a lot of attention, particularly the destruction of tropical rain forests. We are still discovering the vital links between forests and the chemical components of the earth's atmosphere.

Yet, if trees could laugh, undoubtedly they would be laughing at us. Most of the trees on this continent are older than the humans who unthinkingly threaten the existence of the trees. Many of the trees predate the widespread use of fossil fuels, and some even stood firmly in the soil before our nation was born.

But the trees would also be weeping. The human race has carelessly chopped down giant forests as well as giant trees. While we have made this nation great, we have diminished our environment and ourselves in the process.

This report lays the groundwork for future legislation to reverse the deforestation of Michigan. Once the hardwoods were king in southern Michigan: now our furniture factories must import hardwood from other states and countries. Once the trees helped keep our air clean; now they struggle to cope with our polluted air, and often succumb to its ravages.

I trust that, working together, we can use this report as a springboard for a better understanding of our environment and for the development of meaningful legislation.

Sincerely,

Vernon J. Ehlers

VERNON J. EHLERS
State Senator

(4/90)

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Local Action on Global Problems

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EXECUTIVE SUMMARY

A strong scientific consensus has developed that human activities have altered the global carbon cycle. These alterations have raised intense concern over potential long-term changes in our atmosphere, especially the possibility of global warming. Uncertainties about global climatic change concern the magnitude and timing of warming and implications for the earth's plant and animal life, physical environment, social structures, and economies. Additional uncertainties exist about the ways in which climatic changes may be curtailed. However, a variety of options have been devised as possible solutions and controls.

The scientific community's work in the area of global climate change has influenced policy makers in Washington, D.C. Recently proposed federal legislation addresses issues related to global climate change, specifically global warming. Several of these proposals emphasize the use of forest management practices as part of a larger effort to better control atmospheric pollution. Some deal with improving the conditions of urban forests and their direct and indirect effects on the environment, while others deal directly with prevention of global warming and the contributions forest practices may make to that endeavor. Concern at the federal level has been mirrored by concern on the state level. State policy makers want to know if innovative forest management techniques can help alleviate global warming.

Forests play a critical role in the carbon cycle and have direct impact on atmospheric conditions. Perhaps the best evidence that forests influence the global atmosphere is the great amount of CO_2 that is added to the atmosphere through deforestation and associated effects. For this reason, forest management strategies can help alleviate the global warming problem in a number of different ways.

First, research has demonstrated that trees improve the quality of air. Although some research has identified the emission of potential pollutants from trees, these emissions are minimal in comparison to the beneficial effects of trees. Among the direct beneficial effects of trees are their ability to withdraw carbon dioxide (CO_2) from the atmosphere, provide oxygen (O_2) and trap some pollutants that may be contained in dust particles. Trees absorb CO_2 until they die and decompose, at which time, they begin to release CO_2. The ratio of photosynthesis to respiration represents a rough proportion of carbon intake to carbon use. While the tree is healthy and growing, it absorbs more carbon through photosynthesis than it uses in respiration. As the tree matures, it absorbs less and less carbon. Once the tree dies, it releases the carbon over a period of many years.

When properly located, trees can reduce energy demands, particularly for air conditioning, by cooling. This becomes increasingly important in urban environments where trees both sequester CO_2 (or remove it from the air) and provide shade. Therefore, the planting of urban trees can be far more valuable than the planting of trees in rural settings. Moreover, surveys of urban areas indicate that space to plant trees is available.

A substantial amount of research indicates that a massive reforestation effort (especially in urban areas) would improve the local climate and reduce fossil fuel demands for cooling in the summer. But, there is more to sequestering carbon from the air than simply planting trees. Forests that are established as a tool for stabilizing climate demand proper management. Therefore, proper management of forests could be promoted as well as tree planting. Temperate forests managed for high productivity and maintenance of a large amount of standing biomass offer some potential for slowing the buildup of CO_2 and other greenhouse gases. In addition, a workable balance may be reached between improvements in forest management and the use of wood for fuel. By managing forests for wood fuel needs, we may be able to accommodate energy demands and reduce fossil fuel use, thereby actually decreasing the amount of CO_2 released into the atmosphere.

The use of forests alone, as a means of stabilizing climate change, appears to be infeasible. Yet, used in conjunction with efforts to reduce the industrial and agricultural releases of greenhouse gases, forestry practices may yield great contributions. The economic benefits make forest planting more attractive in a state like Michigan which has strong forest industries.

Michigan has a broad and varied forest resource, managed by both the public and private sector. The broad range of Michigan's forest environments require equally varied management techniques. Michigan forest lands include, but are not limited to, very intensive plantations, fruit and seed orchards, private non-industrial woods, and no-management areas. Options for forest management in Michigan include: reforestation of previously forested, but currently abandoned land, and replanting highway corridors and unused agricultural land. Additionally, Michigan's urban forests represent a valuable resource. Improved management of urban forests and nonindustrial private land could result in a variety of benefits.

Both urban and rural forests serve many functions, including wildlife habitats, sources of employment, air and water quality improvers, and recreational opportunities. These sometimes conflicting land uses need to be accommodated. Maintenance of the forests for a broad variety of benefits and uses ultimately results in naturally sound ecosystems.

INTRODUCTION

Michigan's forests have played a central role in the cultural, social, environmental, and historical development of the state. Today, forest resources can make significant contributions to the achievement of important (but often conflicting) goals of maintaining a clean, healthy environment, sustaining economic stability in the state, and ensuring an energy efficient future. The intent of this paper is to focus on some of these potential contributions and provide basic information on trees and forest management for policy makers. Specifically, the paper addresses the prospect of using trees to moderate atmospheric pollution and the greenhouse effect. The paper also discusses the role forest products may have in meeting future energy demands.

Innovative forest management policies have been discussed recently in a number of contexts. Much of the new thinking points to the desirability of enhancing urban forestry programs because of the many benefits of tree planting in urban areas. Among the more immediate and pertinent benefits are the tree's ability to reduce the heat load and to sequester (or absorb) carbon dioxide (CO_2). A tree's ability to sequester CO_2 is particularly important given the role of CO_2 in the greenhouse effect and the excess accumulation of CO_2 in the atmosphere.

This report develops the information on these topics in four sections: *i)* Background information on the biological properties of trees, the chemical properties of the atmosphere, and the interaction between the two; *ii)* Status of forest resources and industry; *iii)* Description of forest management policies affecting Michigan's forest; and *iv)* Options for actions available for improving forest management.

Briefly, the first section describes the relationship of trees to the environment. To understand the influences and effects of trees in the environment, it is necessary to explain the functions of a tree and its essential physiological attributes. Especially important is the contribution trees make to the overall composition of the atmosphere. The interaction of plants, particularly trees, and the global carbon cycle are discussed, with special emphasis on the potential role of reforestation in moderating the rate of global climatic change. A greater emphasis on reforestation could provide a partial solution to the problem of global warming and accumulation of greenhouse gases, thereby improving the atmospheric environment. However, these practices need to be used in conjunction with other actions. The role of forestry certainly may be significant if proper forest management practices are utilized.

The second section provides a description of the forest resources of Michigan. Private, industrial, and government forest inventory resources and uses are discussed, including a description of Michigan's urban forest resource. It is important to acknowledge the available resources before explaining forest policy options. The last portions of this chapter describe ways in which the changing environment affects forests and trees in Michigan.

Forest policies at both the federal and state level are addressed in the third section. The Forest Management Division of the Michigan Department of Natural Resources has taken important steps toward ensuring the long-term productivity of Michigan's forests. Some of the Division's policies and plans are highlighted in the text.

The final section focuses on the various actions proposed within the last few years to improve state, local, and private forest management. The role of forests in promoting economic stability, meeting energy demands, and improving environmental conditions are discussed. This survey concludes with a descriptive listing of many of the options open to state policy makers and their potential for successful implementation.

Forestry interests have often been fragmented, primarily because of the breadth of the discipline. In an attempt to evaluate the interrelationships, the scope of this paper encompasses several facets of forestry including biology, management, economics, and policy. However, this paper has been written in a nontechnical style, with background and illustrations, where appropriate, to assist policy makers in addressing various and complex issues that confront our state.

BACKGROUND

Properties of Trees

Tree Physiology

To understand the ways in which trees interact with the environment, it is helpful to envision the tree as its own system. Figure 1 details the structures (roots, trunk, and crown) most important in controlling tree functions. A tree's root system has a dual purpose. First, roots act as anchors, holding the tree upright and keeping the soil in place. Secondly, and perhaps more importantly, the roots are the subsurface pathways for water and nutrients to be absorbed from the soil via the root tips. The quality and quantity of water and nutrients (including oxygen and carbon dioxide) absorbed by the roots is dependent on the soil quality and type as well as the climate, and directly influences other aspects of the tree's vital processes.

The trunk of the tree, although 80 to 90% nonliving, serves as support and provides the upward pathway for nutrients and water absorbed by the roots. It also is the downward transportation pathway for photosynthetic products derived from the leaves.

The crown of the tree supports the leaves, the "factory" of the tree. Leaves are the photosynthetic apparatus regulating numerous functions of the tree. The system is driven by energy from the sun for the production of food (e.g., carbohydrates) via the photosynthetic process. In this process, green plants use energy from light to combine carbon dioxide and water to make food. It is the most important biochemical reaction on earth since all organic substances originate from this process. Approximately one square meter of leaf surface area produces one gram of product per hour in full sunlight. From the photosynthetic process, the total yield of the earth's vegetation in terms of carbon production is greater than 100 billion tons (Vitousek *et al.*, 1986).

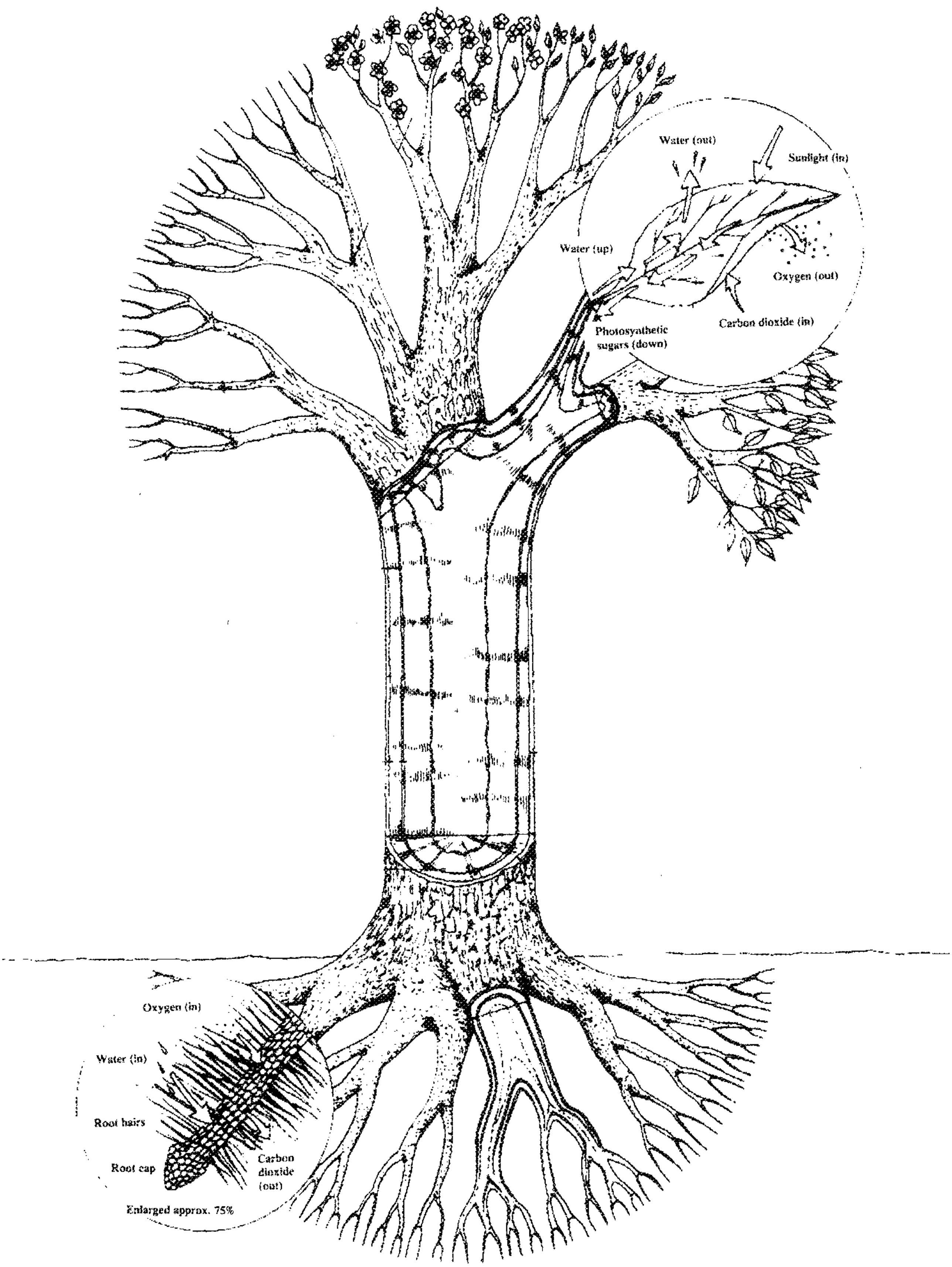
The products of photosynthesis are various forms of carbon, the building block of all constituents of the plant. The forms of carbon may be sugars or carbohydrates. Production of carbon in these forms represents a transformation of carbon dioxide (CO_2) from the atmosphere which is essential to the plant. The plant's ability to transform CO_2 is dependent on many factors, including light, water, nutrients, and concentration of CO_2.

Atmospheric Interactions

An individual tree, like an entire forest, represents a large scale gas-exchange system, transferring materials with the atmosphere through the process of photosynthesis. Plants absorb carbon dioxide (CO_2), produce organic material, and emit oxygen (O_2). Trees can produce an average of 3.5 pounds of oxygen a day. Overall, green plants contribute 70 billion (70,000,000,000) tons of oxygen to the atmosphere each year (Reichle, 1970). Tropical rain forests alone contribute 56% of the total O_2 (39 billion tons) to the earth's atmosphere per year (Hansen, 1988).

As part of the gas exchange capability of trees, some CO_2 is released back into the atmosphere through the process of respiration. In a sense, respiration is the reverse of photosynthesis because oxygen is used and CO_2 is emitted, reflecting the energy used to carry on the functions of the tree. The amount of "food" (carbohydrate) used in respiration is important because it reflects the amount not usable for growth, reproduction, or other vital functions. Respiration can use 30-40% of the carbon products of

Figure 1. Fundamental structure of a tree, showing movement of major components involved in photosynthesis and respiration. Source: Bernatzky, 1978.



photosynthesis in temperate woody plants, and up to the 65% of the total product of photosynthesis in tropical plants—amounting to 20 tons of carbon—per acre. Trees and other plants release CO_2 back into the environment when they die and decompose. Soil microorganisms also respire and add CO_2 to the atmosphere. Thus, all living organisms serve as a source for CO_2 as well as a "sink" for its removal. However, the importance of sequestering carbon by plants and trees outweigh the potential of plants as a source.

In addition to absorbing and releasing CO_2 and releasing O_2, trees produce a variety of substances, some of which are volatile and may be emitted into the atmosphere. Some of these substances may be emitted by destruction of cells or tissue. Others may be released in response to environmental conditions, particularly changes in temperature or vapor pressure. Since these compounds do not seem to be necessary for proper growth and functioning of trees, they are often referred to as "secondary compounds." The importance of these secondary compounds resides in the fact that some are hydrocarbons, similar to the hydrocarbons produced by automobile emissions. Thus, trees may contribute to urban pollution in much the same manner that automobiles do, but on a much smaller scale. Hydrocarbons, whether from natural or man-made sources, may form ozone in the presence of sunlight and nitrogen oxides (also produced by automobile emissions). Ozone has been shown to damage vegetation and has associated human health risks.

Plant hydrocarbons are referred to as biogenic hydrocarbons (BHCs). Ninety percent of BHC is emitted by forests, with 60% being produced by conifers and 30% by deciduous trees. Oxidation of BHCs could account for the production of some ozone. In addition, about 39% of the global carbon monoxide (CO) production may be attributed to the breakdown of BHCs (Zimmerman *et al.*, 1978).

Most attempts to reduce ozone production have focused on decreasing the amount of hydrocarbons released by human activities such as burning fossil fuel. Man-made hydrocarbons account for about 18 million tons of carbon released into the atmosphere each year. Plant-produced hydrocarbons have been estimated to produce 30-60 million tons of carbon a year. However, such figures are deceptive. Even though the volume of BHCs is greater than that of man-made hydrocarbons, their high reactivity and short atmospheric lifetime prevents them from having a direct effect on climate (Chameides, *et al.*, 1988).

To be accurate, approximations of BHC production must account for the environmental conditions which determine the amount of hydrocarbons emitted by trees. However, this is a very difficult task. Production of plant hydrocarbons varies with sunlight, temperature, and humidity. Moreover, emission rates for all varieties of trees vary with latitude, altitude, and season (Zimmerman *et al.*, 1978). Many different types of compounds may be produced, some of which may be more volatile (generally have a lower boiling point) than others. Each tree species, and even subspecies, produces a different array of these compounds. Therefore, different forest types produce dramatically different amounts and types of hydrocarbons, some being more reactive than others. Thus, trees producing more volatile compounds would be responsible for greater hydrocarbon production.

Although the volatilization of BHCs represent a loss of carbon from trees, it is less than 1% of the carbon actually "fixed" or absorbed by the tree (Tingey and Burns, 1980). On a per tree basis, the amount of carbon absorbed by a tree far exceeds the amount emitted, for temperate trees. Although no studies of hydrocarbons emitted by Michigan trees are known, previous studies have identified hydrocarbons emitted by species that also occur in Michigan (Tingey and Burns, 1980). Based on the amount of forested land in Michigan, a considerable amount of hydrocarbons would be emitted, particularly during the summer months (Chameides *et al.*, 1988). Calculations based on emission rates reported by Evans *et al.* (1985) and photosynthesis rates reported by Kramer and Kozlowski (1979), indicate that trees absorb 100 to 1,000 times more carbon than is lost in hydrocarbon emissions.

The Global Carbon Cycle

The element carbon (C) is the basic building block of all life forms on earth. Carbon is primarily available in the form of an atmospheric gas, carbon dioxide (CO_2). When compared with other atmospheric gases (such as oxygen and nitrogen), CO_2 comprises such a small portion of the atmosphere, a little more than .03% by volume, that it may almost be considered a trace gas (Houghton and Woodwell, 1989). In absolute terms, however, it represents an enormous quantity (Table 1a). Further, this quantity should remain relatively constant to maintain delicate environmental balances.

The rate at which carbon moves through the earth's ecosystem varies considerably depending on its form. For example, CO_2 can be captured relatively quickly as plants grow, but released back into the atmosphere as plants die and decay. On the other extreme, carbon can be trapped in animal shells or other sediments that reach the ocean floors and remain out of circulation for millennia. Figure 2 depicts the role of major components in the global carbon cycle. Before the industrial revolution (i.e., mid 1800s), humans had minimal impact on the global carbon cycle, but that influence has been steadily increasing during the last two centuries.

As much as thirty percent of CO_2 formation on land occurs in human-dominated ecosystems. As a result, global patterns of CO_2 have been modified considerably, particularly over the past few decades (Mooney *et al.*, 1987). The carbon cycle can be thought of as a "balanced" system tending toward a state of equilibrium. Prior to the industrial revolution, natural emissions balanced natural losses. However, within the last century, fossil fuel burning has produced a substantial increase in atmospheric CO_2, upsetting the equilibrium of the cycle (Mooney *et al.*, 1987). The atmosphere now contains about 345 parts per million by volume (ppmv) of CO_2, compared with an estimated 280 ppmv in 1800 (Solomon *et al.*, 1985). Between 1977-1987, there was a net annual release of CO_2 into the atmosphere of 1.3 trillion pounds to 5.7 trillion pounds of carbon per year due to tropical ecosystem modification such as agricultural conversion (Detwiler and Hall, 1988). Fossil fuel emissions have contributed 11 trillion pounds of carbon per year over the same period.

If the earth's minerals and nutrients did not move among the components of the earth's ecosystem, they would be unavailable for living organisms. The carbon cycle, like the other biogeochemical cycles such as the nitrogen cycle and the phosphorus cycle, transfers carbon material of various forms through both biotic (living) and abiotic (non-living) components of the earth. As mentioned, the movement within some of these components (e.g., the ocean floors) can be extremely slow. Therefore, the ocean serves as something of a reservoir for long term storage of carbon. The carbon stored in the ocean, atmosphere, and biomass are indicated in Table 1a.

The rate at which carbon moves through the biosphere, also termed the "flux," is indicated for various contributors in Table 1b and in Figure 3. When inputs and outputs into the atmosphere are considered, it is apparent that between 2 and 3 billion tons of CO_2 are added to the atmosphere yearly (Figure 3).

Table 1a. Amount of carbon contained in atmospheric, vegetation, and oceanic compartments (slowly-cycling reservoirs) of the carbon cycle

Total Carbon in the Atmosphere (1982)	795 x 10^9 tons C
Total Fossil Fuel Release (1860-1982)	187 x 10^9 tons C
CO_2 in the Troposphere (1982)	341 parts per million
Historic Atmospheric CO_2 (1800)	280 parts per million
Historic Terrestrial Biomass	9.9 x 10^{14} tons C
Contemporary Biomass	6.2 x 10^{11} tons C
Carbon flux from Land Biosphere since 1800	1.3 x 10^{12} tons C
C in Ocean Surface Layer (0-75m)	695 x 10^9 tons C
C in Intermediate & Deep Ocean	4.19 x 10^{13} tons C
C in Ocean Sediments	1.76 x 10^{19} tons C

Source: Solomon *et al.*, 1985

Table 1b. Flux of carbon through some compartments of the carbon cycle

Gross Annual Ocean CO_2 Uptake	1.18 x 10^{11} tons C
Net Annual Ocean CO_2 Uptake	2.6 x 10^9 tons C
Annual Terrestrial Plant CO_2 Uptake	1.32 x 10^{12} tons C
Annual C Flux from Land Conversion (1970-1980)	1.4 x 10^9 tons C

Source: Solomon *et al.*, 1985

Oceans and vegetation are the primary means by which carbon is removed from the atmosphere. The largest store of carbon resides in the world's oceans, while most of the carbon at the earth's surface is stored in forests and soils. Not much can be done to alter the uptake capacity of oceans. However, production and destruction of the earth's vegetation may certainly have an effect on the overall carbon balance. For example, it is estimated that each year global forest clearing releases between 400 million and 2.5 billion tons of carbon (Houghton *et al.*, 1983, Detwiler and Hall, 1988). In addition, decreases in soil organic matter were responsible for the release of an additional 110 to 330 million tons of carbon in 1980 (Detwiler, 1986). Burning and decay of cleared vegetation were also responsible for 330 million to 1.4 billion tons of carbon added to the atmosphere that same year (Detwiler, 1986).

However, direct releases are not the only ways that CO_2 is added to the atmosphere. For example, a loss of forest land represents a loss of CO_2 uptake capacity. Since both reductions and increases in forested areas are largely controlled by human activity, humans can exert extensive control over this aspect of the carbon cycle.

Forests are in a sense "the lungs of the planet." By taking up CO_2 through their photosynthetic gas exchange properties, trees provide a "sink" for carbon and provide long-term storage of carbon in the biosphere. When trees are cut, and forests destroyed, the carbon is oxidized and released into the

Figure 2. Schematic diagram of the global carbon cycle. Modified from Solomon et al., 1985.

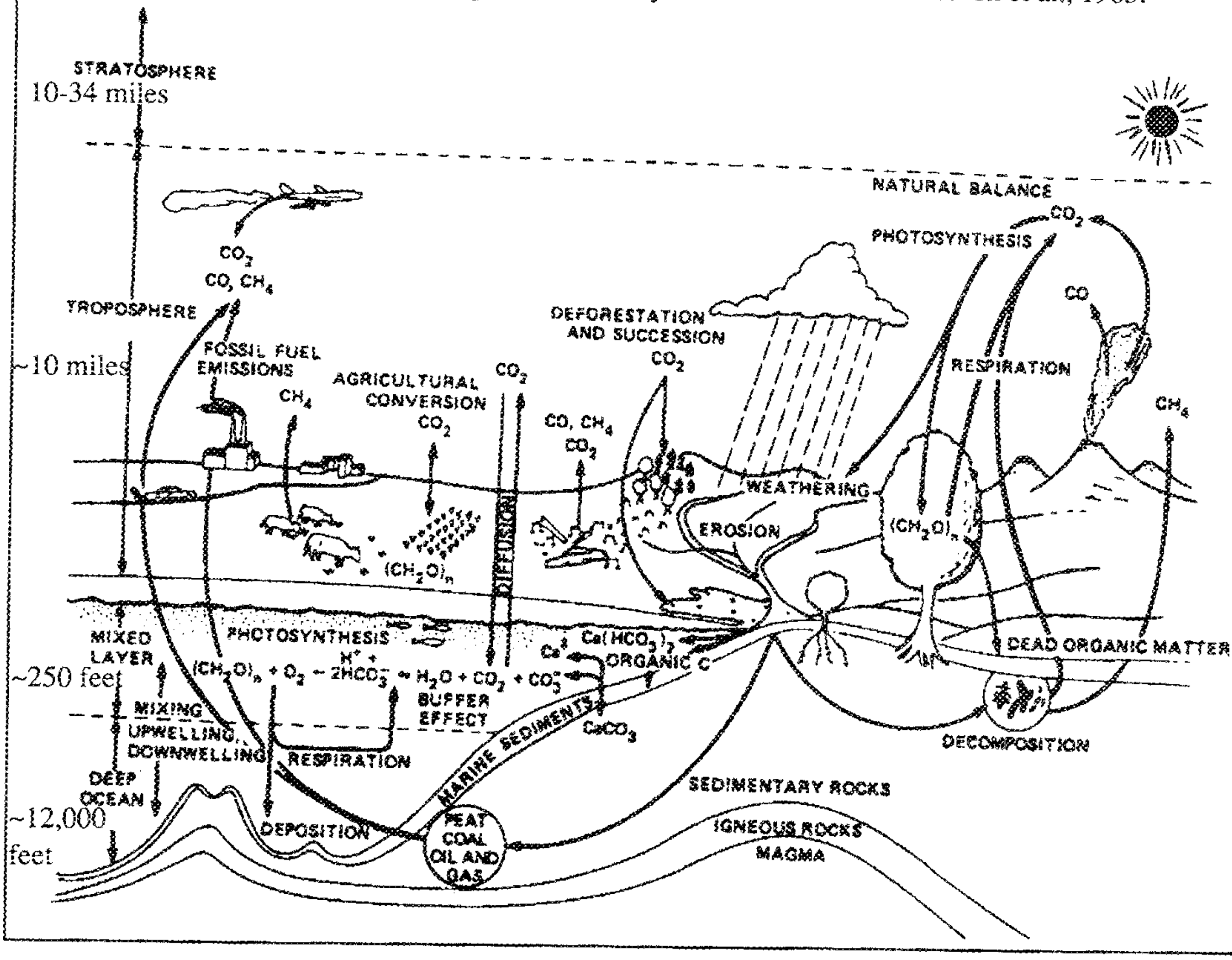
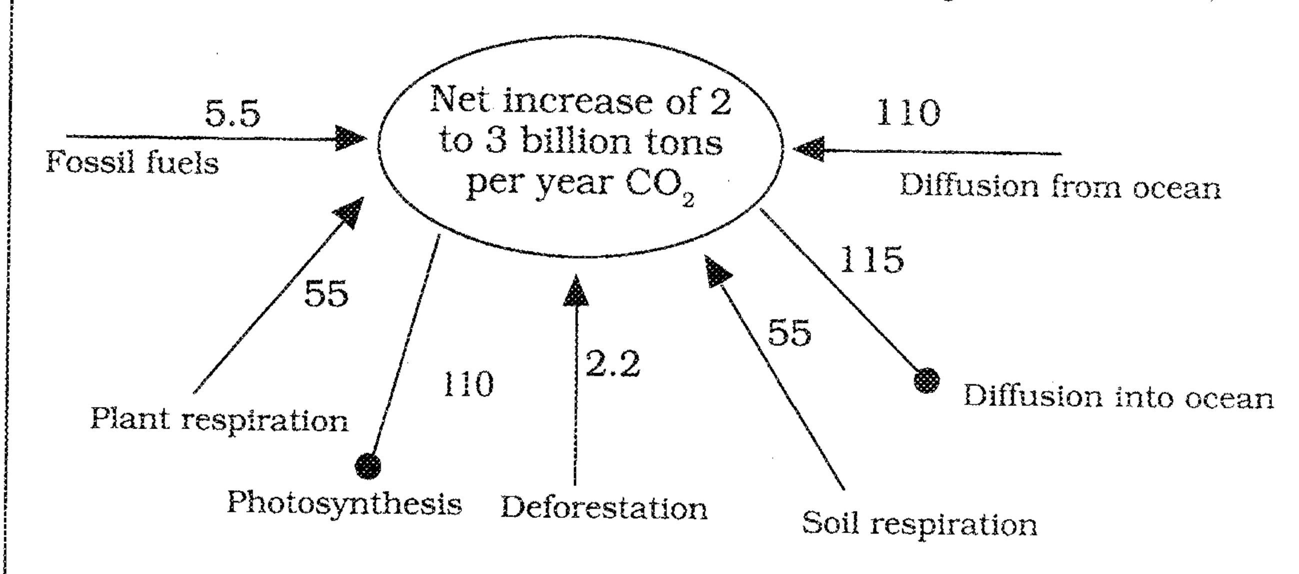


Figure 3. Annual Carbon Fluxes (in billions of tons). Adapted from Houghton and Woodwell, 1989.



atmosphere. This emission is slow if the trees are left to decay or transformed into paper, lumber, or other wood products. The release may be rapid if the trees are burned. On a world-wide basis, the conversion of forest to pasture or agricultural land releases great stores of carbons as carbon monoxide (CO) and CO_2, since conversion typically involves burning.

Evidence suggests that the world's forests have declined by about 2.7 billion acres since pre-agricultural times (from 13.7 to 11 billion acres). Relatively mature temperate forests have declined by 32-35%, but total forest acreage is no longer declining in most industrial countries. However, since World War II, deforestation has been intensified in the tropical regions. Each year approximately 28 million acres of tropical forest are destroyed, primarily for agricultural conversion, but also for fuelwood gathering and cattle ranching. An additional 11 million acres are lost or severely degraded from commercial harvesting (Postel, 1988). On the average for tropical regions, only 1 acre is planted for every 10 acres destroyed. However, the ratio varies greatly, depending on location. For example, in Africa, about one acre is planted for every 29 destroyed, but in Asia that ratio is generally 1 to 5. At current deforestation rates, Repetto (1988) estimates that forests of several countries, among these Costa Rica, El Salvador, Nigeria, and the Ivory Coast, could disappear within 30 years.

The Greenhouse Effect and the Prospect of Global Warming

The composition of the earth's atmosphere appears to change continuously, but over the past two centuries the rate of change has increased considerably, largely from human impact. In general, the effects of changing atmospheric conditions and climatic factors are attributable to several trace gases. Table 2 lists some important atmospheric gases and the contributions they may make to atmosphere and climate. Prominent among these are gases that cause the *greenhouse effect*.

Since the earth is constantly receiving energy from the sun, it must re-radiate an equivalent amount of energy into space to maintain a balance. Carbon dioxide, methane, chlorofluorocarbons, and other gases selectively absorb energy at lower frequencies, retaining some heat in our atmosphere that would otherwise radiate into space (Rind, 1989; Revelle, 1982). Although they make up less than one percent of all atmospheric gases, the concentration of these "trace gases" has been shown to be increasing substantially. Therefore, many atmospheric scientists believe the heat balance is changing and predict an increase in average global temperatures. As used in the popular press, the term greenhouse effect refers to that predicted increase in temperatures. It should be noted that scientists disagree over the amount of change we can expect and the effects temperature increases may have.

According to Dr. David Rind, atmospheric scientist at the Institute for Space Studies, Goddard Space Flight Center, National Aeronautics and Space Administration, the greenhouse effect is:

> *. . . the name for the physical process whereby energy from the sun passes through the atmosphere relatively freely, while heat radiating from the earth is partially blocked or absorbed by particular gases in the atmosphere.* Because the sun is warmer than the earth, its energy is radiated at a higher frequency which is not absorbed well by gases such as carbon dioxide (CO_2) or water vapor. In contrast, these triatomic gases (gases with three atoms per molecule) are effective absorbers of lower-frequency energy radiated by the earth. (See Figure 4.)

The greenhouse effect, per se, is neither good nor bad. If the earth had no greenhouse effect, the planet would be too cold for human life. On the other hand, the predicted problems of global warming and

Table 2. Greenhouse gases and other trace gases that are associated climate changes and atmospheric deposition. A plus (+) sign in the second column indicates that the gas contributes to the greenhouse effect, a minus (-) sign indicates amelioration.

Gas	Greenhouse Effect	Major Anthropogenic Sources	Anthropogenic/ Total Emissions Per year (Millions of Tons)	Approximate Current Concentration (PPB)	Projected Concentration in Year 2030 (PPB)
Carbon Monoxide (CO)		Fossil-Fuel Combustion, Biomass Burning	700/2,000	100 to 200 N. Hem. 40 to 80, S. Hem. (Clean Atmospheres)	Probably Increasing
Carbon Dioxide (CO_2)	+	Fossil-Fuel Combustion, Deforestation	5,500/~5,500	350,000	400,000 to 550,000
Methane (CH_4)	+	Rice Fields, Cattle, Landfills, Fossil-Fuel Production	300 to 400/550	1,700	2,200 to 2,500
NO_x Gases		Fossil-Fuel Combustion, Biomass Burning	20 to 30/ 30 to 50	.001 to 50 (Clean to Industrial)	.001 to 50 (Clean to Industrial)
Nitrous Oxide (N_2O)	+	Nitrogenous Fertilizers, Deforestation, Biomass Burning	6/25	310	330 to 350
Sulfur Dioxide (SO_2)	-	Fossil-Fuel Combustion, Ore Smelting	100 to 130/ 150 to 200	.03 to 50 (Clean to Industrial)	.03 to 50 (Clean to Industrial)
Chlorofluorocarbons	+	Aerosol Sprays, Refrigerants, Foams	~1/1	About 3 (Chlorine Atoms)	2.4 to 6 (Chlorine Atoms)

Figure 4. The Greenhouse Effect.

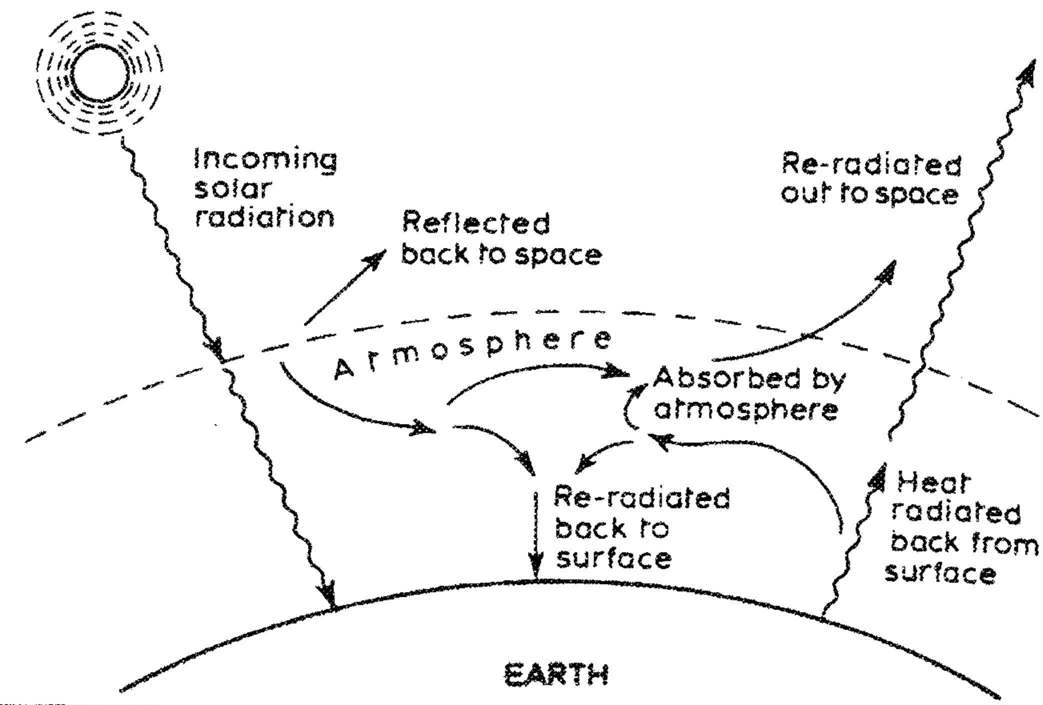
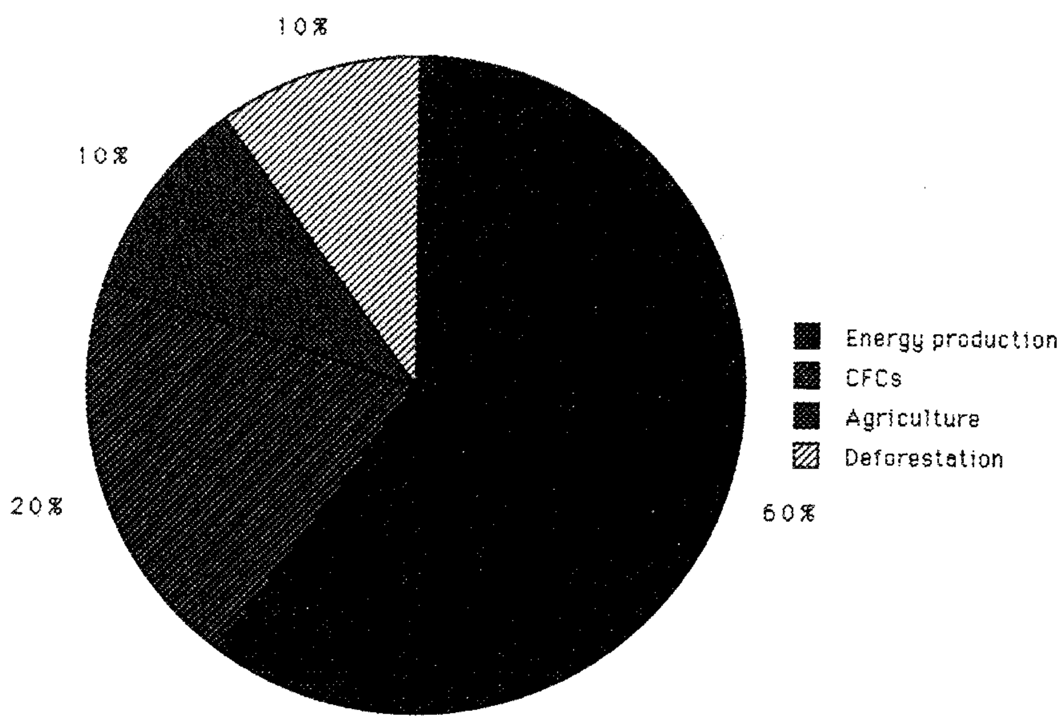


Figure 5. Contributors to Global Warming. Source: Union of Concerned Scientists, 1988.



climate change may result because the greenhouse effect has been *enhanced* by increases in specific trace gases. The contribution of various activities to global warming is depicted in Figure 5.

The forests of the world have direct impact on the greenhouse effect, primarily through their moderation of carbon dioxide concentrations. Of the greenhouse gases, CO_2 interacts with earth's life forms the most, because living organisms are sources of CO_2 in addition to capturing it. The levels of CO_2 in the atmosphere have been increasing about 0.5% per year, as long as records have been kept, in part because of these interactions. Data from Mauna Loa, Hawaii indicate a rise from 310 to 350 ppmv since 1958 (Schneider, 1989a). The major sources of CO_2 in our atmosphere include: respiration of living matter contributing 220 trillion pounds of carbon per year; fires, contributing 4.4 trillion to 11 trillion pounds of carbon per year; and the combustion of fossil fuels, contributing 11 trillion pounds of carbon per year (Mooney *et al.*, 1987). Destruction of the world's forests also contributes substantially to the atmospheric CO_2, adding about 3.5 trillion pounds of carbon per year when the wood burns or decays.

The contribution of methane (CH_4) as a greenhouse gas is particularly important because one molecule of this gas traps outgoing infrared radiation 20 times more effectively than one molecule of CO_2. The annual percentage increase in methane has surpasses the percentage increase of CO_2 in the atmosphere and has accrued 1.1% per year since 1965 (Mooney *et al.*, 1987). Methane appears to be primarily derived from natural rather than industrial activities. For example, natural wetland ecosystems are large sources of methane. It has been suggested that methane production from wetlands may range from 24 billion to 667 billion pounds per year (Mooney *et al.*, 1987).

In addition to natural sources (e.g., forests, swamps, and wetlands) and industrial sources (e.g., coal fields and natural gas wells), methane production accompanies agricultural activities. For example, methane production results from deforestation, as forest vegetation is removed and land is turned over to agricultural uses. Methane production by rice paddies has been estimated at 77 billion to 378 billion pounds per year. Cattle, goats, and sheep contribute 130 billion to 440 billion pounds per year. The increased populations of grazing animals have resulted in a four-fold increase in this source's methane production since 1890. This value is expected to increase as more forest is converted to pasture and grazing land. In addition, termites are responsible for 330 billion pounds per year (Mooney *et al.*, 1987). The values represent a 100% rise in methane concentration in the last 150 years (Cicerone, 1989).

Accuracy of Projections

The "greenhouse effect" appears to be a well documented atmospheric phenomenon. However, there is significant debate concerning the role of human activity in enhancing or increasing the greenhouse effect. There is little dispute among scientists that the CO_2 concentration in the atmosphere has increased 25% since 1850. Further, the average global temperature has increased (33°F) in the same period. Many scientists believe that there is sufficient evidence to suggest that the increased CO_2 levels have contributed to the increase in average global temperature, and that we are in effect witnessing an increased greenhouse effect. However, some scientists disagree, suggesting that data are still incomplete and not fully understood.

Scientists disagree primarily over the amount, extent, and rate of climatic changes that may ensue because of changes in atmospheric gases. Yet, certain facts stand out. For example, the level of CO_2 in the atmosphere has been steadily increasing for the past century, as have the levels of CH_4, nitrous oxides, and other gases. In addition, global forests, an important carbon reserve, are being rapidly reduced. However, some scientists suggest that public concern is stronger than the scientific data.

Michaels (1989) believes that global warming has not occurred to the extent projected by some greenhouse gas theories and that existing data will not support projections of future warming. Similarly, Hanson *et al.*, (1989) found no significant trends in climate temperature data in the continental U.S. over a 93-year period. Increasing autumn precipitation was the only significant trend to indicate a climate change.

However, a number of equally reputable scientists argue that climate changes are inevitable and that the planet's course toward global warming on a monumental scale has already begun. According to some, the effects cannot be underrated. For example, Mintzer (1987) states that a global warming of even 35°F could alter the Earth's climate to an extent outside the range observed in the past 10,000 years. Hansen (1989) feels that a causal relationship exists between global warming and the greenhouse effect, and that its possible to witness a 37°F rise in the next 50 years. Many of the scientists who believe global warming is occurring, or will occur, have based their predictions on highly sophisticated computer models of the earth's atmosphere and weather systems. These "general circulation models" create possible scenarios related to climatic change. Several different models have been developed by different researchers. All agree that a doubling of atmospheric CO_2 would increase global temperature by 5-9°F. However, considerable debate exists as to the specific regional distribution of climatic changes.

Urban Forestry and Urban Trees

Urban forestry is a specialized branch of forestry concerned with the cultivation and management of trees in urban environments. Urban areas constitute 69 million acres in the United States and are increasing by 1.3 million acres a year (USDA, 1982a). Many, if not all of these urban lands include trees as individual plantings, landscape plantings, and parks. In fact, the total area of "urban forests" in the United States exceeds the size of the largest national forest. Traditionally, urban forestry has fallen into the realm of the horticulturists and landscape architects. Recently, however, urban forestry has begun focusing on the tree's environment rather than single trees, and incorporating basic ecological principals and traditional forestry approaches.

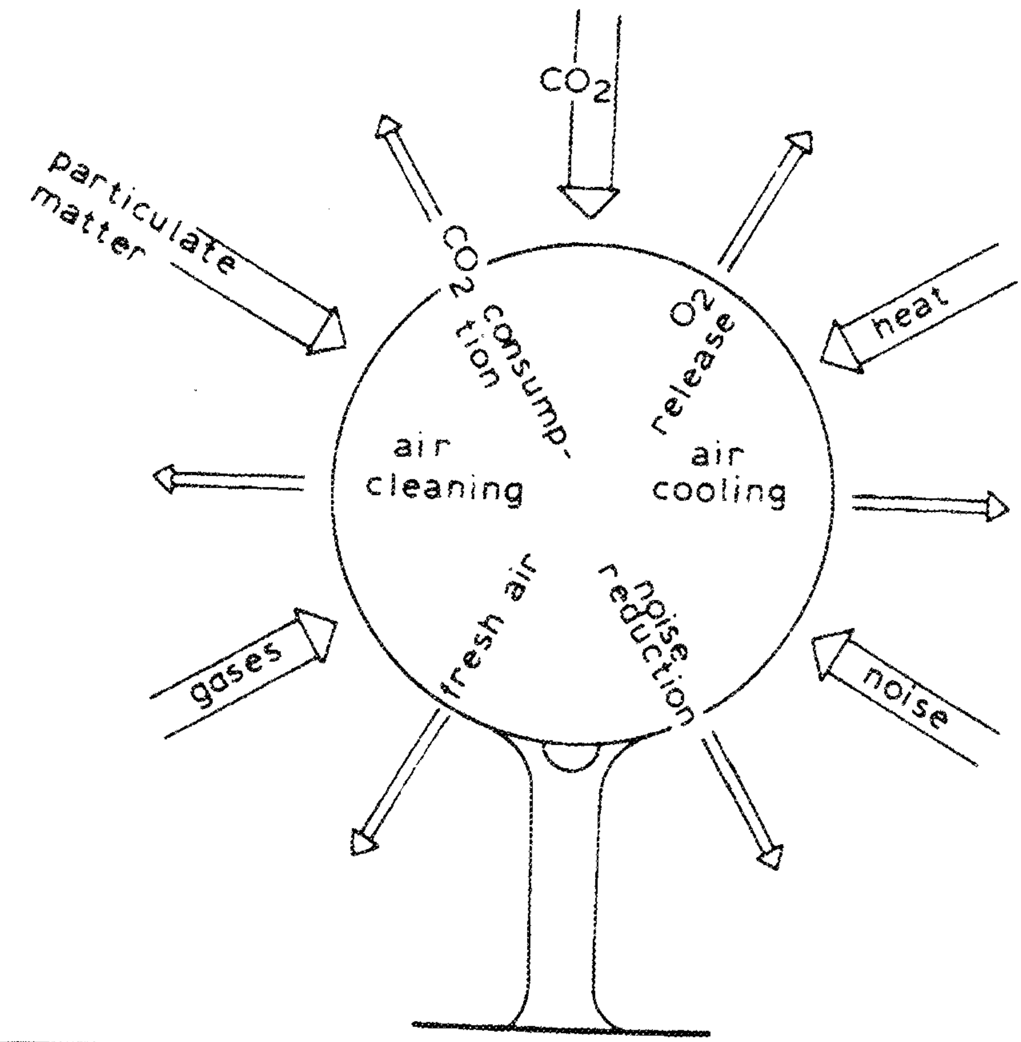
Reforestation efforts in urban areas can help reduce concentrations of CO_2 in the atmosphere in several different ways (Figure 6). Urban trees are capable of directly sequestering carbon and indirectly reducing the production of carbon from energy demands and the related burning of fossil fuels through shading. However, tree plantings in cities have declined in recent years. Moll (1987) found that in the urban forests of 20 cities, on the average, only one tree is planted for every four removed. For a third of the cities, only one in eight trees lost is replanted.

Trees as Moderators of Urban Air Pollution

The role of trees in the removal of gaseous pollution and particulate from the atmosphere has been examined by a number of researchers. For example, studies suggest that high concentrations of certain pollutants may be neutralized through plant metabolism. Additionally, trees can act as dust filters, removing large amounts of suspended particles from the air. However, there is great variation in species tolerance to pollutants, particularly to automobile emissions.

In terms of capturing carbon and providing other amenities, urban trees are 15 times more efficient than rural trees. The American Forestry Association states that one tree can absorb approximately 13 pounds of CO_2 a year and that 2.6 tons of carbon per acre may be captured by urban forests (Sampson, 1988). Additionally, in urban areas, tree-lined streets can remove more than 26,515 dust particles per gallon of air (Bernatzky, 1978).

Figure 6. Some Attributes and Functions of an Urban Tree. Source: Bernatzky, 1978.



Trees as CO_2 Absorbers

As described above, the natural gas exchange properties of plants and trees have a significant effect on the carbon cycle. As long as a tree photosynthesizes, it is a "net importer" of carbon. Young, rapidly growing forests absorb large amounts of CO_2 and assimilate it as biomass. Trees (and forests) continue to take in carbon as they grow, but the rate generally declines with age. Nevertheless, all living trees serve as reservoirs of carbon. Even very mature forests take in CO_2, although a greater percentage is used in respiration. Until a tree dies, the ability to assimilate carbon outweighs any CO_2 emission. Thus, trees may play an important role in reducing the load of CO_2 in the atmosphere.

Estimates of the amount of carbon forests are capable of sequestering vary widely, from 2.02 to 6.1 tons of carbon per acre per year (Marland, 1988). The amount of carbon taken up is a function of species, site conditions, locations, and management scheme, among other factors. As mentioned above, faster growing trees are generally more efficient in sequestering CO_2 than slow growing trees. For example, one acre of fast-growing plantation sycamores in Georgia has been estimated to remove 3.03 tons of carbon per year (Marland, 1988). However, there are exceptions. Silver maples grow quickly, yet they are relatively inefficient at sequestering CO_2, absorbing approximately 2.02 tons of carbon per acre per year (Marland, 1988). Based on good site and growing conditions in the Pacific Northwest or the southeastern United States, Sedjo (1989) suggests that 2.5 tons of carbon a year can be extracted by one acre of plantation forest (no particular species). Others estimate that eucalyptus and pines are more efficient and can absorb 4 tons of carbon per year per acre (Booth, 1988; Machado and Piltz, 1988). The highest documented carbon fixing rate for exotic (or non-native species) in the United States is 5.26 tons of carbon per acre per year. However, small scale experiments have predicted that 6.1 tons of carbon per acre per year can be removed from the atmosphere by loblolly pine after genetic tree improvement (Marland, 1988).

Other forms of atmospheric pollutants such as nitrogen and sulfur compounds may be taken up directly by trees from precipitation. Compounds like sulfur dioxide and other water-soluble gases are taken up through the leaf surface pores in the same way CO_2 is taken up for photosynthesis. Therefore, trees may improve the local atmospheric conditions by using potential pollutants in ordinary plant processes.

Trees as Dust and Particulate Collectors

Dust particles, or particulates, cling to rough or hairy leaf surfaces of most vegetation. Therefore, the large and irregular surfaces of trees are very efficient dust collectors. As little as one hectare (2.47 acres) of spruce plantations could remove 32 tons of dust per year. Pines are even more efficient than spruce, capturing 36.5 tons of dust a year per hectare. In studies by Penham (1978), beech trees were found to be the best dust collectors, removing 68 tons a year. Further, trees and their leaves can cause air turbulence which encourages particulates to "precipitate" or fall out. Because trees are also used as windbreaks, some additional particulate matter is trapped in this manner. Clearly, trees are useful moderators of dry particulate pollution, but species selection is an important consideration when assessing their value.

Tree Shade and Lowering Energy Use

Trees can directly affect the immediate climate within an urban area (the microclimate), particularly by reducing the amount of heat absorbed and retained by buildings and other urban structures. In so doing, trees moderate the so-called *urban heat-island effect* (Akbari *et al.*, 1988), reducing the need for air conditioning. One way trees lower the ambient temperature is by shading. They also lower the air temperature by *evapotranspiration*, the process in which water vapor is evaporated from a leaf's surface (Bernatzky, 1978).

Tree planting in conjunction with the move to buildings colored to reflect light and heat (i.e., albedo modification) may save at least 20% of residential cooling energy use, 12% in small commercial cooling energy use, and 5% in large commercial buildings (Akbari *et al.*, 1988). Parker (1981) estimates that air conditioning needs in Florida can be reduced by 50% if trees are used in landscaping. Akbari *et al.*, (1988) estimate that air conditioning related energy demand could be reduced by 24% in a Chicago home and 29% in Minneapolis through strategic planting of trees. Shrub planting alone, reduced cooling needs for Arizona houses by 30% (Meier, 1989).

Monetary savings are also quite substantial. In 1985, the American Forestry Association compiled a rough estimate that the values of an average 50-year-old urban tree would supply: the savings of $73 in air conditioning, $75 in soil erosion and storm water control, $50 in air pollution control, and $75 for wildlife shelter (Ebenreck, 1988).

In cool weather, trees reduce the need for heating by slowing evaporative cooling and by providing protection from the wind, snow, and rain. As windbreaks planted around houses, trees can reduce heating energy use by 10%-50% (Robinette, 1977). By reducing energy demand for both cooling and heating, trees indirectly reduce CO_2 emission from electricity generation to an extent that may exceed the amount of CO_2 sequestered by urban trees (Akbari *et al.*, 1988). It is believed that the combination of trees and albedo modification could prevent 66 million tons of CO_2 from entering the atmosphere due, in part, to these energy savings. Thus, the heating and cooling functions of trees become as or more important than the ability to sequester CO_2.

The cost of conserved energy (CCE) is very low for planting trees and preparing white surfaces (i.e., albedo modification). Akbari *et al.*, (1988) estimate that the CCE of tree planting at 0.2 to 1.0 cent per kilowatt hour (kWh). That amount contrasts with the CCE for more energy efficient appliances at 2 cents per kWh. The cost of conserved carbon (CCC) runs about 0.3 to 1.3 cents per pound of carbon for tree planting, 2.5 cents per pound for efficient electric appliances, and 10 cents per pound for a ten-mile per gallon improvement in automobile mileage (Akbari *et al.*, 1988).

Urban forestry practices may have a direct influence on the atmosphere, and careful management of urban forests offers an inexpensive way to reduce carbon emissions. The many other desirable attributes of urban trees make a renewed focus on urban forests a promising means of addressing a number of conservation concerns. However, urban environments are unique and each site may need to be evaluated to ensure the appropriate trees are planted. For example, the type of tree used in an urban setting depends on soil type, amount of soil compaction, rainfall, insects, and tree diseases. Lack of attention to these details may cause trees to be planted that cannot survive in the selected urban environment. This topic will be evaluated in greater depth later in this paper.

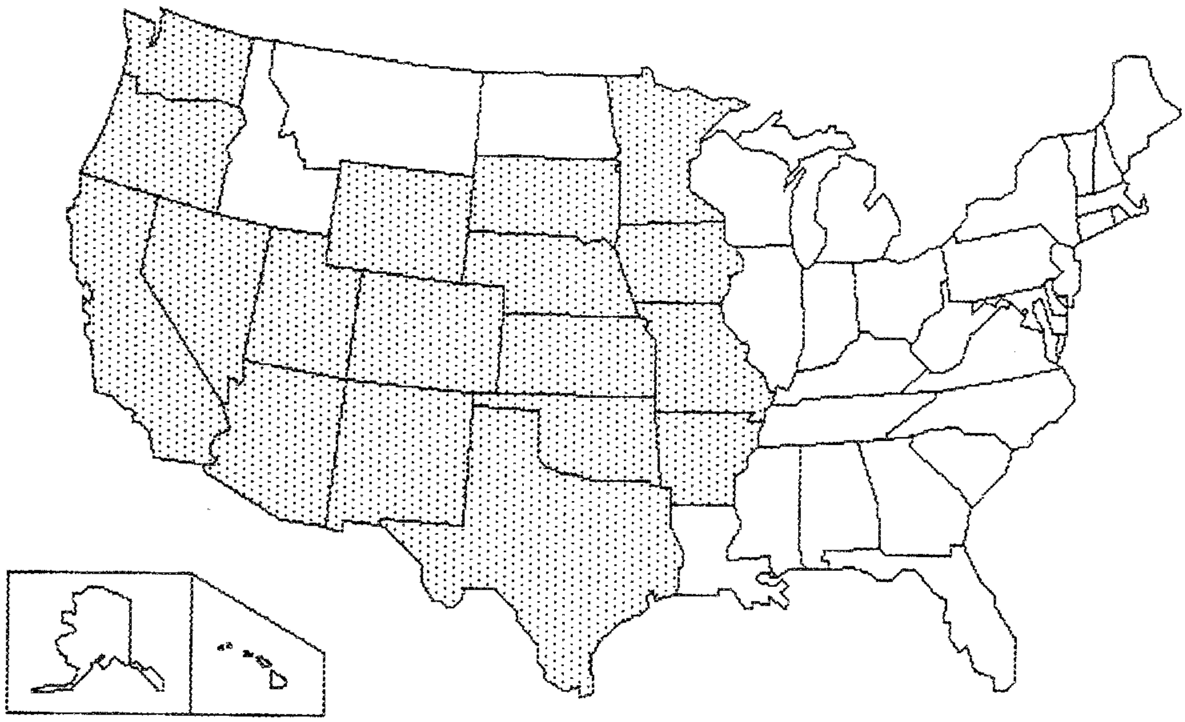
Reforestation

Reforestation Estimates for the Removal of CO_2

Since estimates vary as to the amount of carbon the world's forests are capable of sequestering, it may be difficult to determine the extent of reforestation necessary to absorb a given amount of carbon. Current research estimates that the net annual increase of CO_2 in the earth's atmosphere is 2 to 3 billion tons. According to Sedjo's (1989) predictions, 1.8 million square miles (mi^2) of trees or 1.15 billion acres would be needed to remove this amount of CO_2 from the atmosphere and store it. This area is roughly equivalent to the size of Australia, or the area identified on the map in Figure 7a. Such plantation efforts would be considered as "stabilizing" the global greenhouse effect by removing 2 to 3 billion tons of CO_2 into the atmosphere, off-setting the net annual increase.

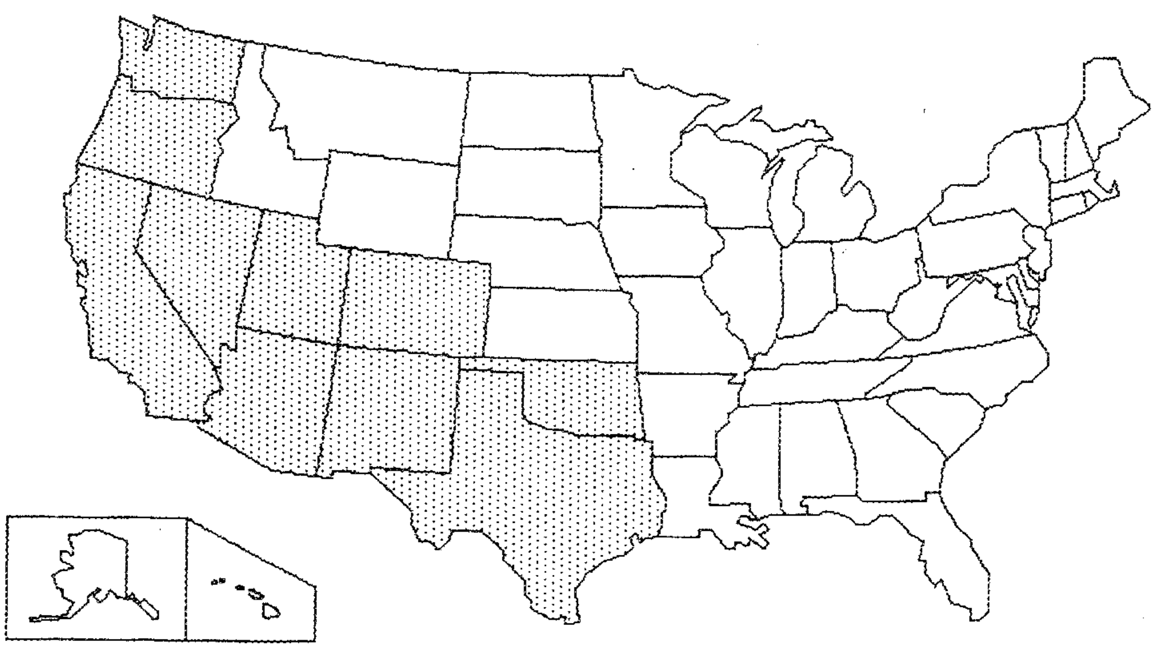
Marland (1988) estimates a more efficient up-take of CO_2, suggesting that about 1.2 million mi^2 forests (740 million acres) would be required to tie up annual increases of CO_2 (Figure 7b). According to Marland (1988), however, 2.7 million mi^2, or 1.2 billion acres of rapidly growing, well managed plantation forests would be required to sequester <u>all</u> the 5.5 billion tons of carbon released annually (Figure 7c). Houghton and Woodwell (1989) estimate that the reforestation of land areas approximately equal in size to the state of Alaska (570,833 mi^2) would result in the annual storage of 1 billion tons of carbon.

Figure 7a. Sedjo's estimate for total area needed for reforestation to offset the annual 2 to 3 billion tons of carbon added to the atmosphere. Source: Sedjo, 1989.



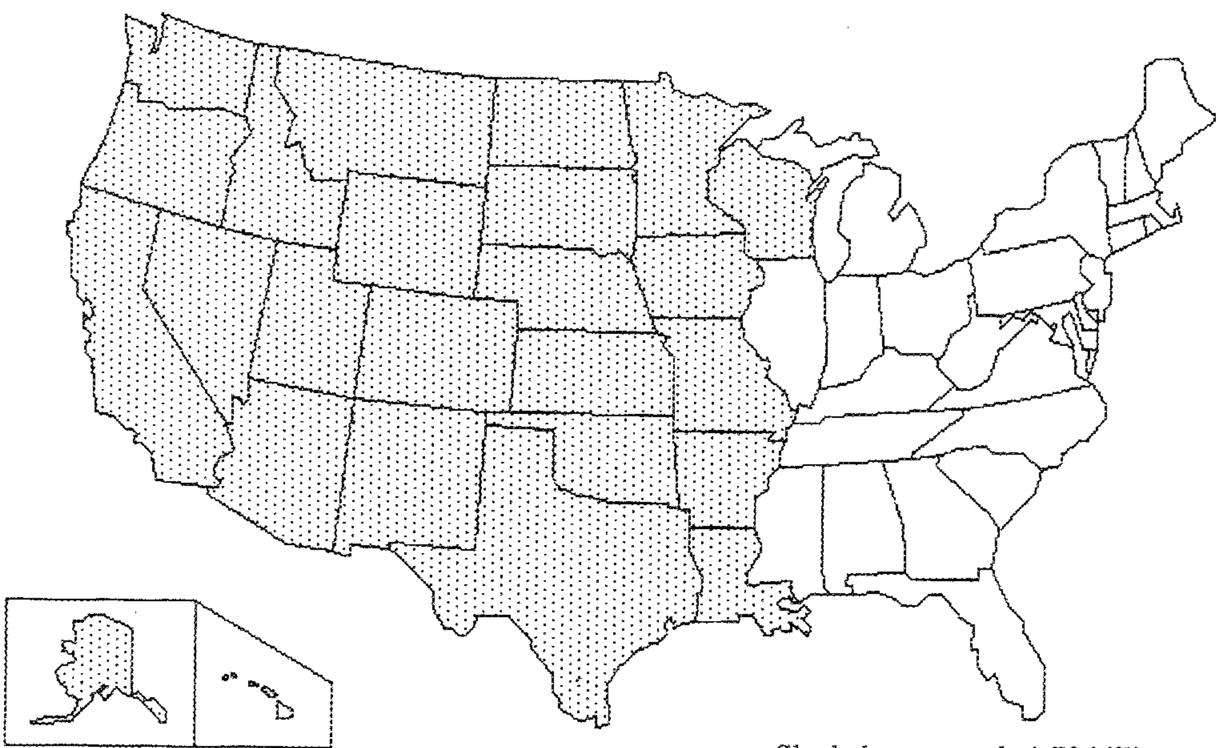
Shaded area equals 1.15 billion acres

Figure 7b. Marland's estimate for total area needed for reforestation to offset 2 to 3 billion tons of carbon added to the atmosphere annaully. Source: Marland, 1988.



Shaded area equals 740 million acres

Figure 7c. Marland's estimate for total area needed for reforestation to offset the annual imput of 5.5 billion tons of carbon released annually. Source: Marland, 1988.



Biomass and carbon accrual change regionally, and so sequestering ability will change regionally as well as with different growing conditions. For example, tropical forests assimilate carbon at a rapid rate since they are often growing the entire year and can concentrate very large amounts of biomass. Brown and Lugo (1982) estimate that an unharvested, old-growth forest in the tropics, contains approximately 36 tons of carbon per acre and that an open forest (fewer trees, any age) contains roughly 13 tons per acre.

Again, the end use of trees will determine the role of plantations in the global carbon cycle. Plantations for sawlogs and veneer are more effective in sequestering carbon because of the *long rotation period* or the long period of time a tree grows before it is harvested. In addition, these wood products are slow to decay, and continue to hold carbon long after the tree is harvested. Thus, they are part of the carbon sink. Fuelwood plantations are probably at a steady state. That is, the amount of carbon released by burning can be recaptured by new plants. However, fuelwood plantations require re-planting soon after harvest to make growth rates similar to removal rates.

It is important to stress that many estimates of carbon accumulation by forests consider only fast-growing, "short rotation species." These trees usually mature in about 50 years or less. Such short rotation species require more maintenance and re-establishment efforts than longer lived trees if they are to sequester carbon as projected.

Implementation

As information has been accumulated about the possible adverse effects of increasing greenhouse gases, many different proposals have been made for increasing new tree plantations to reduce CO_2 in the atmosphere. Implementing any of the proposals to plant trees to offset accumulation of greenhouse gases represents a monumental effort. The estimated acreage and number of trees required suggests a massive employment of people to accomplish the task. Moreover, the land required for this planting effort may be difficult to obtain or convert. Much suitable land is now used in agriculture and may be unavailable for forest planting. Further, most of the deforested land is converted directly to agriculture and supports hundreds of thousands of people (Janzen, 1988). Other sites that are currently unforested may simply be incapable of supporting forests or may be unproductive.

Procuring the land for tree planting could generate land use conflicts and disputes over resource allocation. Rather than attempt to reforest productive agricultural land, or land devoted to wildlife habitat, some proponents of tree planting suggest that reforesting abandoned farmland or previously forested land should be given priority attention (Akbari *et al.*, 1988; Marland, 1988). Other areas such as highway corridors and urban areas could also be considered. In 1976, the United States had roughly 173 million acres of land currently not in production, but having adequate rainfall to support forests.

One attempt to initiate new planting efforts is the Global ReLeaf Program, sponsored by the American Forestry Association. The idea is based on estimates that there are 100 million "free" tree spaces available in the United States (Global ReLeaf, Undated). The AFA has asked each state to sponsor a state-wide program to plant 2 million trees by 1992, and estimates that 40 billion kilowatt-hours of energy can be saved by these new trees.

In the case of the tropical forests, there are currently 3.3 million square miles of total deforested land in the tropics. Roughly 1.8 billion acres are currently unused and could be reforested (Grainger, 1988). Over 500 million acres were once forested and could be restocked. Replanting efforts of that magnitude could demand social modification and changes in long-standing practices of "shifting agriculture" or converting forest lands for food crops. Great social and demographic adjustments would be necessary for large reforestation projects in the tropics, since much of the marginal land supports large numbers of people.

To ensure the rapid growth, and hence optimum carbon fixation of plantations, several measures may be necessary. Irrigation and fertilization are two frequently used treatments in plantation forestry and orchard management which add substantially to costs. With the exception of Christmas tree plantations and seed and fruit orchards, Michigan does not generally use these types of management techniques due to logistical and economic considerations (Shetron, 1989). However, these techniques may need to be instituted if plantation forestry is used in Michigan for CO_2 sequestering. Establishment costs for plantations are expected to vary from a minimum of $93 per acre to over $400 per acre (Sedjo, 1989).

Other drawbacks to massive reforestation include aesthetic and wildlife considerations. In temperate regions, tree plantations are far less favored than natural forests, because plantations may tend to unbalance natural processes and eliminate certain wildlife habitats. A recent conference sponsored by the Pacific Northwest Research Station, USDA Forest Service, addressed the issues of old growth forests and wildlife habitat relationships. One of the principal topics examined was whether or not old growth tree stands sustain a unique wildlife population. The conference identified a number of species (including the spotted owl, the Vaux's swift, the red tree vole, and the flying squirrel) that appear to be strongly associated with old growth habitats or that reach their greatest numbers in ancient forests. However, scientists do not know if this means that these animal species are completely dependent on old growth forests (Booth, 1989).

Another issue of concern relates to the planting of single species forests (monoculture) in massive reforestation efforts. Forests dominated by one tree type can be prone to insect infestation and experience reduced resistance that may lead to widespread disease and mortality. For plantations, species selection becomes crucial to maximize productivity and carbon sequestering ability in an economically-sound manner. Still other problems may occur when new forests are planted in areas that did not previously support trees, or if the types of trees that are introduced cannot naturally grow in the selected region. In general, leguminous species would be favored because of their ability to fix nitrogen, thereby reducing the need for fertilization. Tropical species like *Leucana* absorb carbon at the relatively high rate of 11.8 tons dry weight carbon per acre (Marland, 1988), but this species is a native of tropical forests, and would survive only in a limited region of North America. Nitrogen-fixing species native to North America (though not specifically to Michigan) include black locust, alders, bayberry, and honeylocust, among others.

For CO_2 reduction purposes, desirable species are those that maintain a high photosynthesis rate. Conifer species are capable of photosynthesizing longer into the year, and even in the winter if temperatures are sufficient. Studies by Weide (1962) indicate that the dawn redwood (not native to Michigan) photosynthesized at a higher rate and respired minimally, making it more desirable and efficient in capturing CO_2 than beech, oak, pine, or spruce.

Although scientific understanding of processes in biological systems is constantly improving, the ability of scientists to accurately predict the rate of most of these processes is poor. There are many unknowns about the way in which the biosphere will respond to the increasing concentrations of CO_2 (Solomon, 1986). For example, laboratory studies have shown that photosynthesis, growth, and respiration increase at both the individual tree level and the community level with increases of CO_2 (Bazzaz, *et al.*, 1985). The effect of higher CO_2 appears similar to fertilizer. However, CO_2 increases have also been shown to initiate plant aging which is accompanied by increased respiration and additional release of CO_2. Moreover, increases in CO_2 accelerate decomposition of wood and other organic matter (Kramer and Sionit, 1987). Despite many estimates of CO_2 uptake and sequestering, neither the effects of increased CO_2, nor the ability to offset these increases can be estimated with precision.

STATUS OF FOREST RESOURCES AND FOREST INDUSTRY

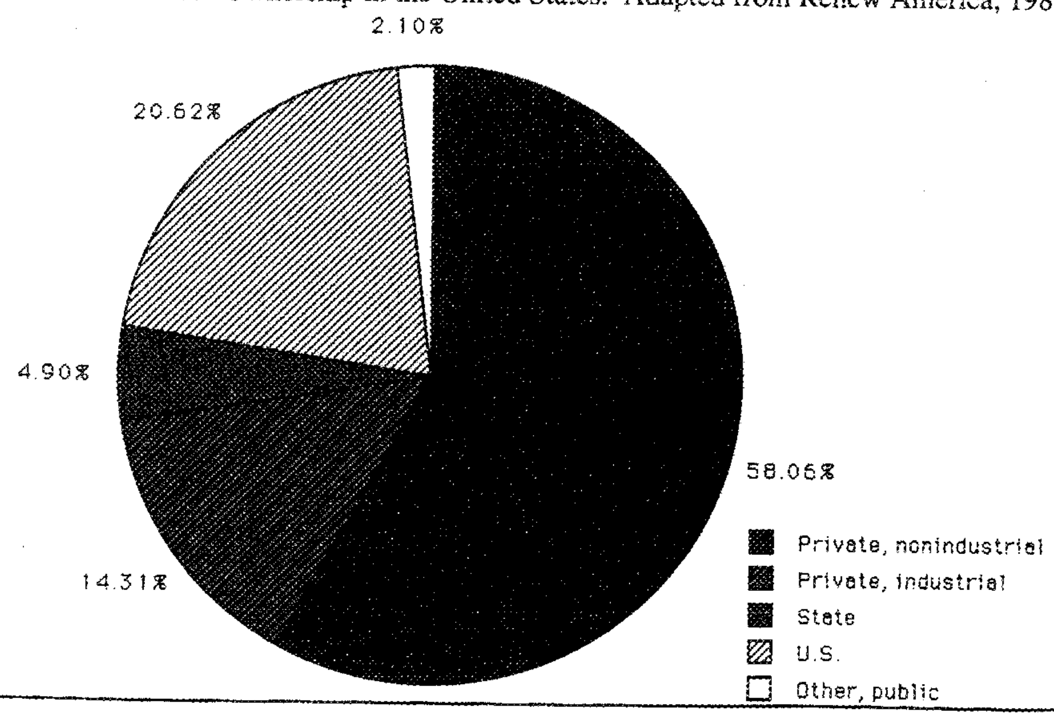
As mentioned above, proper forest management requires a knowledge of the regional and ambient environmental conditions and the limitations resulting from this environment. Conditions such as soil type, amount of rainfall, and regional temperature are referred to as the "forest resources." Forest resource management is complex and demands information about the function of the forest including its economic, environmental, and biological character, as well as its social attributes. With the aim of identifying possible strategies to affect global warming or other environmental problems, the following sections briefly describe the forest resource in the United States, and more extensively in Michigan.

United States

The United States has approximately 740 million acres of forested land (Renew America, 1989). Roughly 65% of this can be considered commercial forest land. Commercial forest land refers to land capable of sustained production and not withdrawn from timber production. Sustained production means the natural, biological capability of growing 20 or more cubic feet of wood fiber per acre per year. The ownership of commercial forests in the United States is indicated in Figure 8. Of the total forested areas, roughly 240 million acres, or 33%, are federally owned and managed (Renew America, 1989). Twenty-three million acres are state forest land. There are 68 million acres of private industrial forest, and small landowners possess 277 million acres (Renew America, 1989).

In general, forest resources in the United States are intensively managed and oriented toward production. The 480 million acres of commercial forests in this country are highly productive. Although this acreage represents only about 10% of the world's forest area, it supplied nearly 25% of the world's industrial forest products in the late 1970s (USDA, 1982b). However, total forest area in this country has been slightly decreasing in recent years. Over the past 25 years, fire, diseases, timber harvesting,

Figure 8. Commercial Forest Land Ownership in the United States. Adapted from Renew America, 1989.



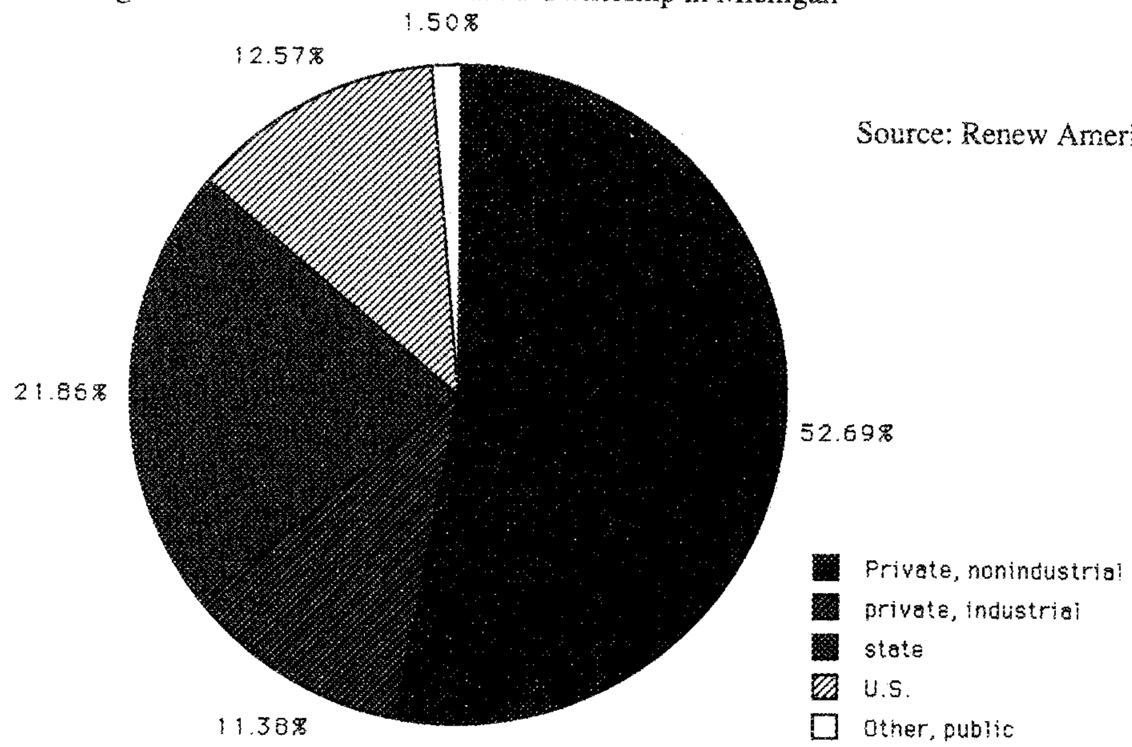
construction, and clearing the land for urban and agricultural development have been responsible for a 5% decrease in forested area. Projections suggest a reduction of 19 million acres by the year 2030 (Meeks, 1982).

The forest industry provides a strong economic base to many areas of the country. Approximately 1.6 million people are employed in forest products companies in the United States (USDA, 1989).

Michigan

Approximately 50% of the land area in Michigan is forested, including 17.3 million acres of commercial forest land, the fifth largest amount among the states (Smith and Hahn, 1986). Sixty-four percent of Michigan's forested acreage (11.1 million acres) is in the hands of private owners (Potter-Witter and Haraty, 1988; Renew America, 1989). Most of these private forests (7.6 million acres) are owned by individuals, while 3.5 million acres are owned by the forest product industry. The state of Michigan manages 21% or approximately 3.6 million acres of the total forest lands in Michigan. The USFS manages 2.4 million acres of Michigan forest land in three national forests (Figure 9) (Potter-Witter and Haraty, 1988). The remaining acreage belongs to other public institutions. Table 3 illustrates the small amount of change in Michigan's timberland ownership during the 1980s.

Figure 9. Commercial Forest Land Ownership in Michigan



Source: Renew American, 1989.

Table 3. Percentage of Timberland by Type of Ownership, 1987 and 1980.

	1987	1980
Industry	20%	20%
Farm	18%	18%
Other private	26%	27%
State	21%	20%
Federal	14%	14%
Other public	1%	1%

Source: Potter-Witter and Haraty, 1988

Regionally, the distribution of forests is disparate. Projections from a Michigan forest inventory indicate that the Upper Peninsula is about 84% forested; 61% of the northern Lower Peninsula is forested; and 17% of the southern Lower Peninsula is forested (Smith and Hahn, 1986). This distribution has directly affected the location of key facilities in the wood-products and other forest-related industries.

Michigan's 12.9 million acres of hardwood timberland represent about 37% of the total hardwood forest acreage in the upper lake states (Michigan, Wisconsin, and Minnesota). Michigan's 4.2 million acres of softwood timberland account for almost 40% of the lake states' softwood resource. These facts underscore the value of Michigan forest resources and help explain the healthy growth of Michigan's forest industry in recent years.

Michigan has a myriad of forest types. The diversity in Michigan forests is associated with differences in latitude, soil, and climate. For example, the southern part of the state supports the northern limit of the oak-hickory forest formation, with beech-maple (the southern analogue of the northern hardwood forest) occurring on better sites. These forests are strictly hardwoods, with oak, maple, beech, basswood, and ash species predominating. Prairie fringes are found, particularly in the southwest part of the state, along with the noted oak savannas or oak openings. In northern parts of Michigan's Lower Peninsula, the northern hardwood forests begin, eventually giving way to the boreal forest. The northern hardwood forest contains many of the previously mentioned species in addition to aspen, pines, birch, and hemlock to varying extents. The boreal forests are primarily conifer, consisting of fir, pines, hemlock, and spruce as well as some birch, aspen, or maple (Albert *et al.*, 1986).

Maple-birch is the largest forest type in the state covering 36% of the total 17.3 million acres (Smith and Hahn, 1986). The aspen forest type represents 19% of the total (Smith and Hahn, 1986). Table 4 lists the major forest types and acreage in each.

Most northern forests are in a state of constant flux primarily because of temperature changes. Oak, for example, migrated into the Lower Peninsula 10-12,000 years ago, while spruce and jack pine have been here for about 14,000 years. Species like hemlock are 'actively migrating' across the Upper Peninsula of Michigan and westward. As the climate warmed following the close of the last glacial period about 10,000 years ago, some tree species migrated at an average of about 6-38 miles per century (Roberts, 1989). Beech migrated about 12 miles in 100 years, while spruce distributions were traced at 125 miles in 100 years.

Michigan's forests are generally less than 100 years old, but forest types differ in age (Smith and Hahn, 1986). In addition, certain old growth forests, most of which are in the Upper Peninsula, have trees representing 400-500 years of growth. The presettlement forest of Michigan supported many species. However, over time, the species diversity has been reduced considerably (Stearns, 1988). Much of the forests of the Lower Peninsula were severely logged during the last few decades of the 1800s until very little remained. Repeated fires then burned throughout the landscape, giving a competitive edge to those species able to withstand this type of severe, repeated disturbance. As a result, oaks and aspen dominate large sections of the landscape that previously supported pine and hemlock forests (Whitney, 1987). Since fires do not now burn with the frequency and intensity of the post-logging fires, a noticeable shift in species composition is taking place again.

The majority age class of the trees strongly determines the value of a forested area. For example, 51% of the maple-birch forest type is over 70 years old, while 50% of the aspen is under 30 years old as a result of forest fires. Generally, the former forest type represents suitable timber while the young aspen provide pulpwood and game habitat. However, older growths may be most suitable as habitat for a number of nongame animal species. Timber resources for the state are stored in the future since most of the softwood and hardwood resources are immature. In all, 69% of the growing population of trees is 12 inches or less in diameter (Smith and Hahn, 1986).

Michigan's hardwood industry has traditionally been dependent upon the availability of saw timber (sufficiently sized logs for lumber), but the removal of a majority of the mature hardwoods over the decades has resulted in a relatively immature forest. Recent technological advances have provided increased utilization of smaller hardwoods; for example, the capability for pulping hardwoods and the creation of composites such as flakeboard and waferboard (Chappelle and Webster, 1988). Thus, hardwood forests may be harvested and used, for a variety of products regardless of age and size of tree.

Table 4. Area of land by land class of major forest types in order of abundance in Michigan.

Forest Type	Area*	Proportion of total
Maple-Birch	6,162.5	36.0%
Aspen	3,325.4	19.0%
Oak-Hickory	1,731.3	9.9%
Elm-Ash-Soft Maple	1,268.2	7.3%
Northern White Cedar	1,185.4	6.8%
Jack Pine	832.9	4.8%
Red Pine	668.1	3.8%
Balsam Fir	607.4	3.5%
Black Spruce	512.7	3.0%
Paper Birch	366.6	2.1%
White Pine	218.9	1.3%
Others	462.2	2.7%

* measured in thousands of acres

Source: Smith and Hahn, USDA Forest Service General Technical Report NC-112, 1986.

Presently, growth exceeds harvest for both hardwoods and softwoods in Michigan. Annual harvests average 45,000 acres on state forestland. Of those, 39,000 acres are naturally regenerated; that is, no effort is made to plant new trees, allowing natural succession to take place. Only 4,000 acres of trees are planted each year (artificially regenerated) on state forestland. The remaining 2,000 acres are essentially abandoned. However, these areas are often low productivity sites where little would grow back naturally. These could be planted, but often remain untended because of state budget limitations (Reuschel, 1989). Changes in this harvest ratio may result when unexpected incidents, such as serious insect damage, occur leading to additional harvesting as salvage operations.

Forests as an Economic Resource

<u>Statewide</u>

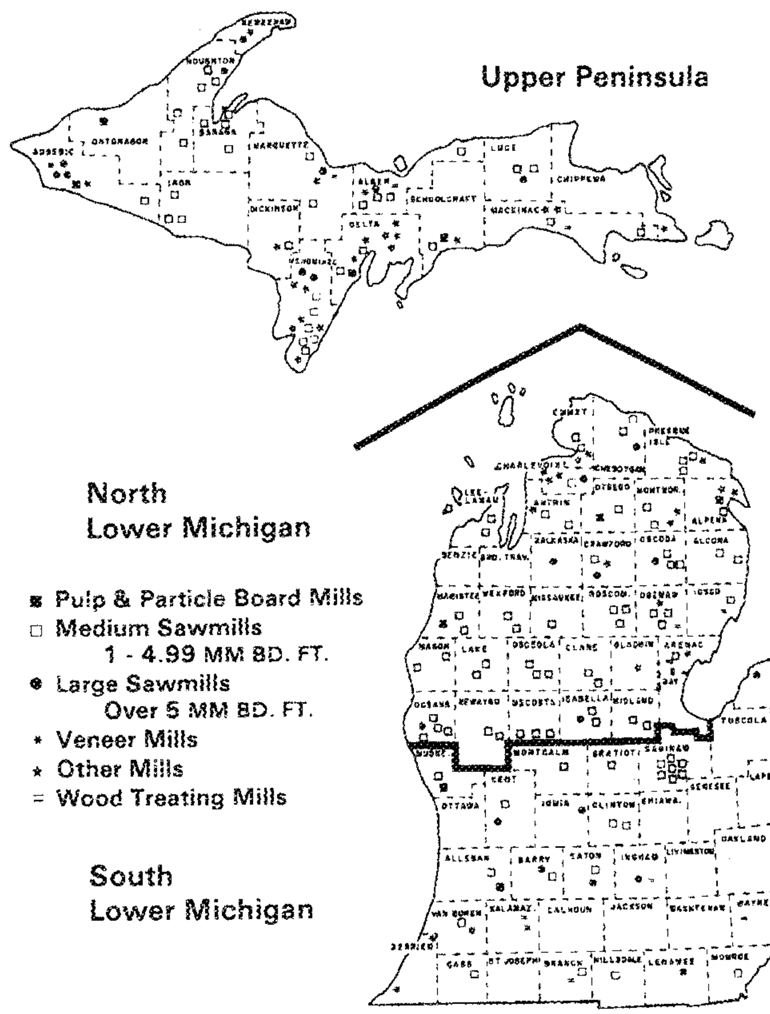
Since 1980, forest industry expansion has been impressive in the lake states, particularly in Michigan. The expansion involved $1.25 billion dollars in investment, and 3,500 to 4,000 new direct jobs, resulting in 8,500 to 9,000 new employees in the forest products industry of the state (Webster, 1989). The forest industry in Michigan employs more than 63,000 people directly. Taken together with associated "spin-off" jobs, there is a total of 145,500 jobs generated by Michigan's forest industry (DNR, 1987). A number of factors have contributed to this expansion, including growing timber resources, technological advances, and the favorable economic conditions afforded by Michigan's location, particularly regarding transportation costs.

In Michigan, standing timber is estimated at 20,558 million cubic feet of growing stock, approximately 75% of which are hardwoods (Smith and Hahn, 1986; Michigan Department of Commerce, 1986). Net timber growth, after allowing for losses from insects, disease, fire, etc., is 753 million cubic feet per year (Potter-Witter and Haraty, 1988). On a per volume basis, growth exceeded harvest and was almost twice the removals in 1986. The growing stock volume was 10% higher than that reported in 1980 (Smith and Hahn, 1986), underscoring the fact that Michigan's forests are still relatively young, but rapidly growing.

Michigan has nearly 300 sawmills producing 600 million board feet of lumber a year. These are located mainly in the forested regions of the state. But forest-related industries are not limited to that region. Over 460 secondary wood product plants are located in southern Michigan (Michigan Department of Commerce, Undated). Since 1981, new forest industry investment includes 6 pulp or paper facilities, 4 composite wood production facilities, 35 secondary or integrated manufacturing plants, and at least 6 wood energy facilities (Webster, 1989). Of the employment in forest-related activities, 47% was in paper and allied products, 28% in lumber and wood products, and 25% in wood furniture and fixtures (James *et al.*, 1982). Figure 10 indicates the distribution of major mills in the state.

Although it represents only a modest portion of total state economic activity, the forest products industry is a significant contributor to the economic base of some rural areas. Examining the future of Michigan's forest industry, Pedersen and Chappelle (1988) suggest that the forest product industry will expand in the upper Great Lakes region (Michigan, Minnesota, and Wisconsin) at a rate approaching 3% annually between 1985-1995. The increase will be well above the expected performance of the overall economy of the entire region. The study indicates that the region has adequate resources to meet expected demands. Good growth prospects in the industry include wood furniture, structural particleboard, aggregated hardwood dimension and flooring, special product sawmills, pulp and paper, and paper coating and glazing (Pedersen and Chappelle, 1988).

Figure 10. Location of Mills in Michigan. Source: James *et al.*, 1982.



Products from Michigan forests are numerous and varied. Lumber and wood products are used for quality wood furniture and fixtures, pulp, and paper. Softwood lumber is used for utility poles, landscape timbers, and building products. Composite wood products are manufactured from aspen and dense hardwood chips and flakes. Particleboard, oriented strand board, fiberboard, and waferboard are just a few of the composite wood products made from the harvest of Michigan forests. Other forest products and their values are listed in Table 5. The highest valued forest product in 1984 was domestic firewood, estimated at $103 million. The volume of pulpwood in 1984 was 174 million cubic feet (ft^3) valued at approximately $90 million (Potter-Witter and Haraty, 1988).

Michigan is one of the leading states in Christmas tree production, harvesting 5.2 million trees in 1986 at a value of $50.7 million. Approximately 160,000 acres are managed by 2,000 Christmas tree growers in Michigan. Approximately 14,000-15,000 acres per year are planted, or roughly 14 million trees (Roshetko, 1989). Christmas trees are planted on short rotations, with few of them exceeding 10 years of age. In terms of contribution to global carbon cycle, these rapidly growing trees account for considerable sequestering, but for brief periods of time. If Christmas tree growers continuously rotate and replant their crop, then some continuous amount of carbon is sequestered. However, limitations in total quantity of CO_2 sequestered depend on replanting cycles and the size to which the trees are allowed to grow. In contrast, much of Michigan's older hardwood forests and mature pine plantations provide long-term storage of carbon.

Table 5. Forest Production and Value in Michigan. Data is from 1984, except Christmas trees (1986).

Product	Volume	Value
Pulpwood	174 million ft3	$ 89,956,000
Sawlogs	91 million ft3	$ 87,378,000
Veneer Logs	4 million ft3	$ 12,236,000
Post & Poles	3 million ft3	$ 4,092,000
Other Roundwood	12 million ft3	$ 5,411,000
Mill Residues	.1 million ft3	$ 1,588,000
Domestic Firewood	2 million ft3	$ 102,781,000
Christmas Trees	5 million trees	$ 50,700,000

Source: Potter-Witter and Haraty, 1988.

The wood products industry in Michigan is diverse in character, process, and endproduct. Complete descriptions of forestry-related economic resources in Michigan have been published in several documents by the Forest Management Division of the Department of Natural Resources and the Department of Commerce. The following sections will provide information on a few of the more important segments of the industry.

Private-Industrial

Pulp and Paper

Pulp and paper manufacturers own a considerable amount of Michigan forest land. The two largest private landowners in the state of Michigan are Mead Corporation, owning 700,000 acres, and Champion International owning 380,000 acres, both in the Upper Peninsula.

On Mead's land, approximately 12,000 acres a year are cut. Harvesting by Champion is highly variable. Since the Upper Peninsula consists of diverse forest types, various forest techniques are used. According to James Okraszewski and John Dahlberg, woodlands managers at Mead and Champion respectively, hardwoods are cut and harvested with selection cuts as a general practice, and allowed to naturally regenerate. Only stands with sufficient natural advanced regeneration are cut. That is, stands with enough seedlings or saplings to sustain the forest for another generation.

Champion uses only hardwood, and thus, has no replanting program (Dahlberg, 1989). Mead, on the other hand, has an extensive reforestation program. On pine, spruce, fir, or low-productivity northern hardwood sites, clearcutting and replanting are common. The bulk of planting has been red pine and jack pine, and between 3,500 and 4,000 acres are planted each year. At least 50% of the hardwood sites have been converted to conifer plantations (Okraszewski , 1989). Within the last decade, planting emphasis has shifted from strictly conifer to include hardwoods, particularly from improved seedlings and seed sources. Some examples are hybrid aspen, varieties of European larch, and native tamarack. With this technique, the various adapted species could be used to replant sites that were previously difficult to revegetate.

Hardwood Industry

Although forests in Michigan and throughout the northeast have recovered from the severe logging and harvesting that took place 100-150 years ago, they bear little resemblance to earlier forests (Stearns, 1988). In many areas, the percentage of current forested area is equal to or greater than presettlement forest, but generally the economic quality of the forest has declined.

Oak had long been the favorite of furniture manufacturers, and Michigan has been noted for its valuable oak resources. However, oak resources have been depleted and oak regeneration has been minimal (Whitney, 1987). As a result, other species such as ash or sugar maple are now being marketed quite aggressively. The lack of oak may be a direct result of changes in management technique. Oak regeneration has specific site requirements and requires certain management techniques (i.e., burning).

The hardwood forests of Michigan have been important resources to furniture manufacturers for almost a century. Additionally, hardwood lumber is used for cabinets, packages, and material-handling products. This industry has been especially important in the southern part of the state where oak and associated hardwoods, such as hickories or maples, dominate the landscape. Economic projections indicate that the future holds good growth prospects for the wood furniture industry (Pedersen and Chappelle, 1988). Hardwood buyers in the state feel resources are adequate to suit the needs of the industry (Rosner, 1989; Bertsch, 1989).

Michigan is a net exporter of raw forest products, much of it to overseas markets (Vincent, 1989). These exports have raised concerns that intermediate job opportunities are being lost at a local level. For that reason, some have suggested that export bans should be considered. However, according to Jeffrey Vincent, forest economist at Michigan State University, most economists suggest that the economic effects of export bans tend to be detrimental. Generally, one link in the economic chain benefits at the expense of others. By banning exports, the price of logs within the state is driven down, which pleases the mill owner, but not the landowner. Lower prices, in turn, reduce the incentive for the landowner to continue managing the forest for long-term productivity.

Private-Nonindustrial

The nonindustrial private forest landowner (NIPFL) may represent a potential, but untapped, resource of forest products in Michigan. Fifty-five percent (see Figure 9) of the commercial forestland is controlled by the nonindustrial private sector. Michigan has approximately 385,000 private woodland properties under 10,000 acres in size. This is a large resource, yet its fragmented ownership creates a series of difficulties for proper management and timber harvesting. The owners of 21% of this acreage have no intention of ever harvesting timber (Marty, 1985). Very few (10%) of the private forest landowners have turned to professional foresters for advice. Cooperative efforts in education and tax incentives are possible ways of promoting active forest management by the private nonindustrial commercial forest owner.

The federally funded Forestry Incentives Program (FIP) has been in operation since 1974 and is one legislative attempt to encourage NIPFL participation in forest resource management. FIP is a cooperative program coordinated by the USDA Forest Service, Michigan DNR's Forest Management Division, and the USDA Agricultural Stabilization and Conservation Service. Through FIP, 3.4 million acres had been actively treated from 1974 to 1986 (Ellefson and Risbrudt, 1987). Sixty percent of the treatment has been reforestation, and 40% timber stand improvement.

Incentives were provided by federal legislation in 1980 (PL 95-313) creating tax incentives and joint cost-sharing under FIP and the Agricultural Conservation Program (ACP) (Royer and Moulton, 1987). Under this legislation, a 10% tax credit can be subtracted from the amount of taxes owed.

In Michigan, the Farmland and Open Spaces Preservation Act (1974 PA 116) provides tax benefits to certain landowners, including Christmas trees farmers. Lands that qualify and are approved under the Farmland and Open Space Preservation Act are exempt from special assessments for sanitary sewers, water, lights, or nonfarm drainage, unless the assessments were imposed before enrollment in the program (1974 PA 116, MCLA 554.709). In addition, under a development rights agreement, the owner of farmland and related buildings may be eligible for a credit under Public Act 228 of 1975 as amended, being MCLA sections 208.1 to 208.145. Under this Act, the landowner is entitled to claim as a credit against state income tax liability the amount by which the farmland property taxes exceed 7% of the household income. This credit is in addition to a homestead property tax credit which the landowner may claim on the state income tax return (1974 PA 116, MCLA 554.710).

Michigan's Commercial Forest Act (1925 PA 94) provides for the reduction of property taxes for those who intend to maintain, develop, and actively manage a forest through planting, natural regeneration, and other sound forest practices. Under the Act, land owners may seek the DNR's approval for listing property as a commercial forest. The owner of listed land may harvest certain timber resources for commercial purposes, however, the land may not be developed for agricultural, industrial, or recreational purposes. A listed commercial forest must remain open to the general public for hunting and fishing (1925 PA 94, MCLA 320.310).

Urban Forestry in Michigan

The urban forest resource in Michigan is difficult to define partially because it is under varied ownership. Although largely under the auspices of municipalities, urban forests include residential properties, county, and other private sector lands.

A study conducted by Michigan State University's Department of Forestry for the International City Management Association by Kielbaso *et al.* (1988) revealed that only about 38% (400) of the city managers polled in the United States knew or could estimate the number of street trees in their jurisdiction. The reported average number of street trees nationwide was 29,677, and the median was 11,000 per city. Of the 55 respondents in Michigan, 22 indicated that they managed their urban trees systematically. The average number of trees per city in Michigan is 20,343, with a minimum of 500 and maximum of 70,000. The city of Lansing, for instance, has about 40,000 street trees.

The primary tree species in Michigan's cities varies, but generally Norway, crimson, and sugar maples seem to dominate. Ash, honeylocust, and linden are also common in Michigan. Michigan's urban tree species mix is similar to that of other states of the northeast and north central regions of the country. The trend appears toward greater emphasis on faster growing, shorter-lived trees. However, many communities have adopted the practice of planting smaller ornamental trees because of the substantial maintenance costs involved with large trees and because of a desire for trees scaled to the reduced heights of homes in residential neighborhoods (Kielbaso *et al.*, 1988). Nevertheless, ornamental trees may be equally costly for urban forestry use as they are often labor intensive (Kielbaso *et al.*, 1988).

Various criteria for street trees limit the usable species. A variety of species is needed to avoid insect and disease problems. Maintenance and tree care are crucial considerations in the urban forest. Both the survey conducted in 1986 and surveys from 1974 and 1980 indicate that the north central region of the U.S. and the Pacific Coast demonstrate the highest level of tree care management (Kielbaso *et al.*, 1988).

Michigan's urban tree maintenance includes trimming, fertilization, spraying, and repairing, among many other activities to ensure a healthy tree population. In addition to maintenance, emphasis on planting, pest management, and education are important to all urban forests. However, Michigan's urban foresters have divergent management approaches.

The city foresters of Lansing indicate that tree maintenance to prevent property damage or other liabilities related to limb and tree breaks is the single highest priority. Trimming is a major appropriation of their budget. Lansing's trees are selected on the basis of the ability of the tree to withstand an exposed urban environment, particularly wind resistance (Cool, 1989).

The Grand Rapids Urban Forestry Management Department estimates that Grand Rapids has 60,000 street trees. The principal criteria for selecting trees for Grand Rapids is to select those which can tolerate that particular urban setting. For example, urban trees need to tolerate road salts, heat reflected from the pavement and asphalt, and air pollution. The Department attempts to maintain a balance between tree planting and maintenance, although there is no systematic tree maintenance policy. Department personnel estimate that 75% of their time is spent responding to citizen requests for tree trimming or removal. In selecting park trees, the Department tends toward indigenous and ornamental species. These trees are monitored through regular park maintenance personnel as no regular trimming schedule exists. While insects and disease affect the health of Grand Rapids' trees, the greatest difficulties relate to water stress (i.e. too much or too little water) (Paasche, 1990).

According to Dennis Bowles, Forestry Supervisor for the City of Flint, selection criteria for Flint's trees are based on the ambient environment, the root system, and the shape. Flint's trees are exposed to large amounts of air pollutants. Therefore, the Forestry Supervisor has chosen to plant ash, sugar maples, spruce, and pine; all trees that tolerate salt, and car and factory emissions. Trees with extensive root systems are avoided because they can send out roots which may cause future sidewalk damage. Finally, the shape of a tree is important to Flint's urban foresters. Where low profile is desired, shrubby trees, such as flowering crabapple, are selected. Thin trees are often used along streets so as not to block a driver's vision. Although the recent summer drought conditions has effected the health of some of Flint's trees, the city Parks and Forestry Division has tried to select trees which can withstand urban environments and are easily maintained (Bowles, 1990).

In Detroit, tree selection criteria is based on urban environment (soil and air quality) and planting location. The Detroit Parks and Recreation Department plants hardy trees which can withstand salt and variations in air quality. They avoid ornamental trees because of vandalism. In addition, ornamental trees are adversely affected by the city's air quality. Citizens have some input into the kind of trees that are planted in residential areas. However, the city does try to plant one species per block. Trees for parks are primarily selected by whatever is available, however, the city tries to plant trees for shade when possible (Downs, 1990).

The criteria for tree selection in Escanaba are based on indigenous species and those which have shown few problems with disease. According to Jim Larson, Assistant Supervisor of Public Works, Escanaba foresters plant Norway Maples, Marshall Seedless Ash, Locust, and Red Oak. Maintenance is a priority. City foresters plant and replace dead trees in the spring and prune during the winter months.

The trees in Escanaba have been damaged by the droughts of the last two summers. This, along with a caterpillar/pest problem has been the principal impediments to the trees. Apparently, only minor problems exist due to Escanaba's urban setting (Larson, 1990).

To improve urban forestry in Michigan, James Kielbaso, professor of urban forestry at Michigan State University, suggests allocating more personnel and and financial resources to urban forestry, probably via Michigan's Department of Natural Resources. For example, Dr. Kielbaso suggests the development of a position within DNR's Forest Management Division solely devoted to urban forestry (Kielbaso, 1989).

Wood as Energy

Background and Statistics

The use of plant material as a source of energy is as ancient as human use of fire. All types of plants have been used for providing heat, but the energy potential in wood makes trees a particularly valuable source. Worldwide, wood energy is still the primary source of light and heat. Although supplanted by fossil fuel use in Michigan and much of the United States during the past century, there is still substantial prospect for use of wood energy in the state.

Several factors create the opportunity for increased wood energy production in Michigan. First, most forest practices generate some form of waste which can be used as fuel. Removals fall short of growth; therefore, a surplus of forest biomass may exist in Michigan. Management practices incorporating firewood use may enhance stand and timber values and improve aesthetics.

Forest resources available as possible fuel resources in Michigan are: standing timber, post-harvest residues, forest industry residue, urban tree wastes, and sawmill wastes. The quantity of wood resources is estimated at 26 million tons of wood per year. In 1980, it was suggested that 780 million tons could be harvested over the next 30 years, serving 6.8% of Michigan's projected energy requirements in the year 2000 (MERRA, 1980).

The use of wood energy is not restricted to burning. Numerous conversions are possible other than direct combustion in fireplaces, wood stoves, or industrial boilers. It is possible to liquify wood to produce a fuel oil substitute or to gasify the wood to produce a low or medium Btu gas substitute for natural gas. (A Btu or British Thermal Unit is a unit of heat energy required to raise the temperature of one pound of water from 60° to 61° Fahrenheit under scientifically defined conditions.) According to at least one authority, however, direct combustion offers the best opportunity for wood to contribute to Michigan's energy needs (MERRA, 1980).

Less than 4% of the total energy use in the United States annually has been supplied by forest residues and wood wastes. Residues and wastes could supply up to 12% to 16% of the annual energy need, although a limited amount of energy from this source is currently economically recoverable. If all 236 million acres of unused cropland produced energy crops, at 5 tons dry weight per acre per year, the results would be more than 24% of energy feedstocks produced per year (Wright *et al.*, 1989). In 1980, MERRA estimated that 26,000,000 tons of excess wood fiber per year was available for production of energy in Michigan.

Total regional (upper Great Lakes states) output associated with wood energy was estimated to have been greater than $74 million in 1985, and is projected to approach $105 million in 1995. According to resource economists Pedersen and Chappelle (1988), total regional employment associated with wood energy is expected to grow modestly — about 1% a year from 9,000 employees to more than 10,500 between 1985 and 1995.

When burned, wood contributes to the pool of atmospheric CO_2. However, the total contribution of CO_2 could be far less than fossil-fuel burning. Marland (1988) indicates that when fuel wood is used in a true sustained-yield mode, there is no net discharge of CO_2. Growing trees could take in quantities of CO_2 equivalent to what is released by burning. By reducing fossil-fuel use, the continuous use and regrowth of wood could curb increasing atmospheric CO_2. In short, prudent management could allow the forest to sequester amounts of carbon roughly equivalent to amounts released in burning.

Research Into Wood-Energy Systems

The United States Department of Energy has been supporting research in the wood utilization program since 1978, as part of the effort to develop alternatives to fossil fuels (Wright *et al.*, 1989). The interest in wood energy diminished during the mid to late 1980s when fossil-fuel prices stabilized, but is rebuilding with growing environmental concerns. The forest product industry has taken an active role in this area. In the United States there are 27,000 acres of plantation lands held in alliances between private industry and research. (For example, Martin Marietta Energy Systems, Inc. and Michigan State University have a plantation alliance for wood energy research.) These connections could be very useful for continued exploration of the feasibility of large-scale use of wood energy.

Wood fuel is typically a product of intensively cultivated plantation forests. Among the advantages of woody crops for fuel is the fact that most are fast-growing assimilators of carbon. Short rotation intensive culture (SRIC) refers to experimentally grown high-yield forest crops by using hybrid or genetically improved trees (Hansen, 1988). SRIC plantations fix and recycle carbon each time they are harvested and burned, which is about every 10 years. SRIC requires an active management policy, including: site preparation; weed control; short rotation; dense spacing; easy regeneration through sprouting; fertilization; and irrigation (Hansen, 1988). Although the energy produced by plantations of eucalyptus, sycamores, alder, cottonwood, and willow is ten to twenty times the amount required for their production (Garrett, 1980), these practices, especially irrigation, may be costly and are a major limitation to SRIC plantations.

SRIC practices, particularly irrigation and fertilization are not used in Michigan. In addition, some of the tree species often used in SRIC management may not be supported by Michigan soils (Shetron, 1989). However, other species of Michigan trees may be commercially produced for fuelwood. Hybrid poplars appear to be a potentially valuable fuelwood resource in Michigan. These trees are adaptable and relatively tolerant of harsh conditions (Dickmann *et al.*, 1989). For example, hybrid poplars planted in Michigan continue to photosynthesize at high rates even under severe drought conditions.

Research in Michigan has identified genetic differences within the poplar (aspen) species that exhibit the highest photosynthetic rates and highest harvest index (the portion of tree that is usable wood). The harvest index of *Eugeni* was 0.68 and *Tristis* 0.48. First-year growth of these hybrids reached 11.2 feet in height. Additionally, the research shows that the ability to increase biomass production was evident in these plantations after one harvest (Dickmann *et al.*, 1989).

Black locust is another species considered for short-rotation woody biomass crops. This tree is native to the Appalachian Mountains and Ozark Hills, but has been widely planted throughout this country and Europe. In addition to its rapid growth and Btu value, it is a leguminous nitrogen-fixing tree that amends its soil and contributes to the fertilization of the site.

<u>Impediments of Large Scale Wood Energy Systems</u>

A number of energy conservation programs have been established in Michigan with monies from the Federal Petroleum Violation Escrow Fund (also known as the Oil Overcharge Fund). The Michigan Energy Conservation Program (MECP) is one of the state projects supported by these funds through The Office of Energy Programs in the Michigan Department of Commerce under the statutory authority of 1988 PA 305. The MECP administrates several state energy conservation projects including one that promotes the use of wood-energy in place of fossil fuels. The Wood Energy Demonstration Project (WEDP) is in its third and final year of establishing practical energy saving methods through the use of wood-energy systems. The initial installation cost of wood-energy systems is often prohibitive. Therefore, WEDP assists wood-utilization facilities financially, providing grants for the establishment of wood-energy systems. In the last year, WEDP has helped five organizations convert to wood-energy systems including: a producer of preassembled log homes; a particleboard manufacturer; a lumber and furniture producer; a pallet builder; and a medical care facility. Two of the five companies are located in the Upper Peninsula (Nichols, 1990).

One of the impediments to using wood energy on a large scale, such as wood-fired electric power plants, is consumer reluctance. Frankena (1989) describes some problems with the acceptance of wood-fired power plants. Primary considerations include: abuse of forest resource; nutrient loss due to whole-tree harvesting; deterioration of the site surrounding the plant; and the impact of burning refuse-derived fuels (RDF). Whole-tree harvesting may be of particular concern in Michigan as this practice has created soils depleted of nutrients in the past. If wood-for-energy plantations were considered in Michigan, whole-tree harvesting would need to be intensively managed to prevent nutrient poor soils (Shetron, 1989). Frankena argues that the scale of the facility rather than the characteristics of the resource created the severe opposition to several proposed plants, two of which were in Michigan.

The Changing Forest

Possible Effects of Elevated CO_2 on the Forests of Michigan

Evidence suggests that the presettlement forest of Michigan was very diverse, a function of soil type, disturbance history, and climate. During the middle and latter parts of the nineteenth century, extensive harvesting of the forests took place throughout the upper Great Lake states reducing forest diversity. Regeneration of Michigan's forests is contributing to increasing diversity once again, but these are in transition, not bearing great similarity to the original forest (Stearns, 1988).

Since climate and soil are factors in determining forest composition and distribution, the effects of climatic change likely to accompany elevated levels of CO_2 may be considerable. Because of the diversity in species and forest types in Michigan, the changes may also be unpredictable.

Many factors may help to determine the ultimate effect of climate change on a particular plant process or distribution. Elevated CO_2 levels and global warming are likely to increase water-use efficiency in plants (Strain, 1985). Plants lose water through the same leaf openings used to take in CO_2 (i.e., the stomata). When CO_2 levels are raised, stomata close more readily and remain closed for longer periods and less water is lost. Therefore, some species may become adapted to a "new climate" limiting subsequent species shifts (Solomon and West, 1985).

Just as severe logging and associated burning have created the second generation of Michigan forests, climate change could bring about a marked transition in the forests. Research examining the impact of climate change (predicted by some in association with the greenhouse effect) has determined that species distribution would be predictably altered (Roberts, 1989). Since climate and soils are strong determinants of plant distribution, a prolonged warming trend would shift tree distributions northward. In Michigan, the oaks and oak-hickory complexes would move (Smith and Tirpak, 1988). More southern species throughout the continent would become less vigorous. Further, the droughty soil conditions that have been predicted would be likely to render some tree species susceptible to diebacks. Ruderals (weedy species) and species of lower economic value would be likely to expand, since these species are able to exploit many habitat types (Davis, 1989).

On a national basis, a shift in species as much as 370-431 miles over the next 100 years could occur if predictions of global warming come true (Smith and Tirpak, 1988). However, there would not be a direct group shift; that is, the beech-maple complex as we know it would not shift as an entity; rather individual species with particular tolerances would migrate differentially. Thus, changes in composition and the creation of new 'forest types' would occur. The ramifications of such changes would be extensive. Associated wildlife species may be unable to adapt, resulting in the possibility of extinctions. For example, species like the Kirtland warbler that require a particular habitat may be deprived of their nesting sites (Botkin and Nisbet, 1989).

Bottlenecks are reductions in population size such that genetic diversity is limited. The species then become genetically uniform and not easily adaptable to new environments, pests, or diseases. Bottlenecks limit the potential for genetic differentiation and may eliminate highly adapted members of a species. An increase in the atmospheric CO_2 level may cause bottlenecking of certain wildlife populations that already have a limited environment in which to live. Distributions of these species would probably become restricted to small pockets of "island populations." Depending on a number of environmental factors including the type of climate change, the rate of change, the adaptability of the species, and the abundance of a species food sources, the species may become extinct over time (Hartl, 1989).

Although Michigan has over 100 native tree species, they range from very dry-site oak and jack pine to wet site species such as bog spruce and black spruce. In drier sites, the elevated temperature and reduced soil moisture predicted as part of the greenhouse effect could reduce biomass by 77 to 90% (Smith and Tirpak, 1988). As a result of dryness and loss of species, there could be reversion to oak savannas or prairie grasslands in some parts of the state. Under some scenarios of climate change due to the greenhouse effect, bogs could lose their trees and the northern forests comprised of both hardwoods (e.g., oak, birch, maple, ash, etc.) and boreal trees (e.g., conifers, spruce, firs, etc.) could become all northern hardwoods, with the boreal forest migrating farther north. According to Smith and Tirpak (1988), forest changes in forest species and types could be evident in as little as 30 to 60 years.

Possible Effects of Air Pollutants on the Forests of Michigan

The makeup and productivity of Michigan forests could be altered by pollutants not strictly associated with global warming. Since 1985, forest scientists from Michigan Technological University, Michigan

Figure 11a. Sulfate deposition gradient for North Central United States (pounds per acre per year) (Source: EPA/NADP Data 1980-1984).

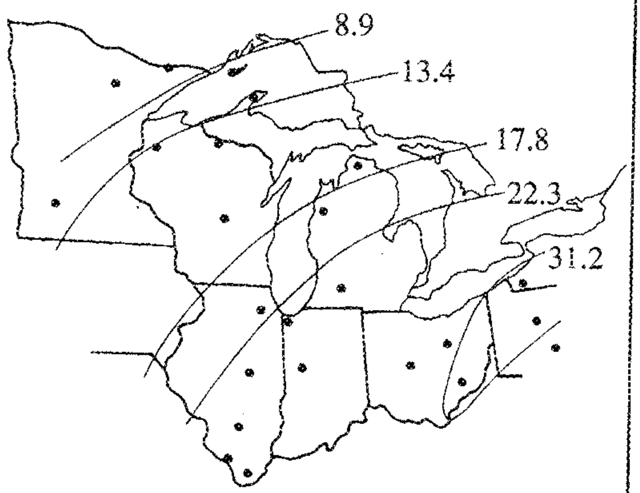


Figure 11b. Nitrate deposition gradient for North Central United States (pounds per acre per year) (Source: EPA/NADP Data 1980-1984).

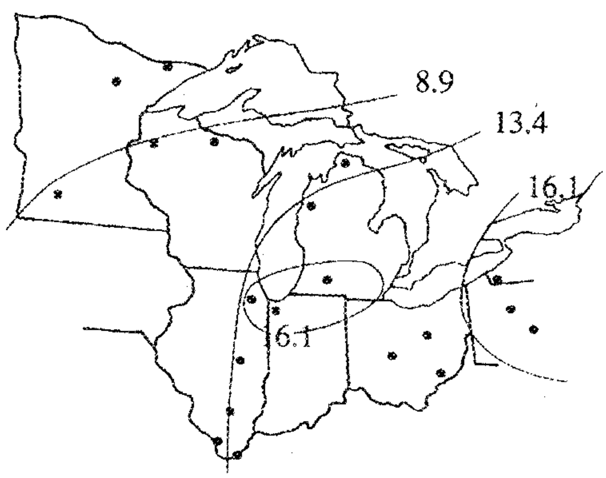
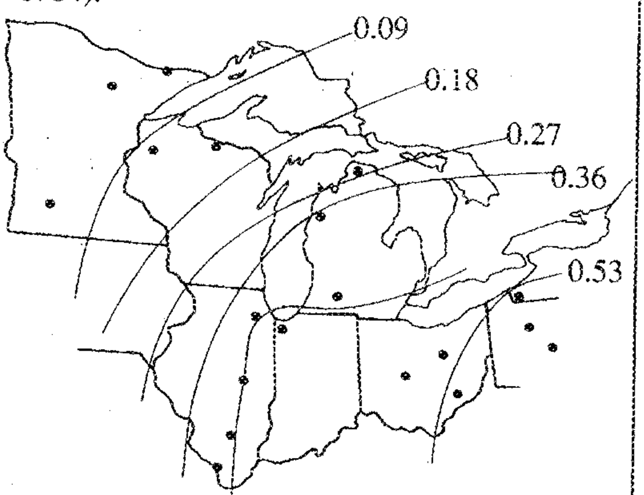


Figure 11c. Hydrogen ion deposition gradient for North Central United States (pounds per acre per year) (Source: EPA/NADP Data 1980-1984).



State University, and the University of Michigan have been conducting research on the effects of atmospheric pollution on regional forest productivity. Previous studies by the Environmental Protection Agency (EPA) indicated that a pronounced trend in pollutant deposition (NO_3, SO_2, and H^+) occurs across the northern lake states (Figure 11). A strong gradient of deposition is evident with these largely man-made sources of emissions, the highest concentration centering around the southern part of Michigan increasing with proximity to regional emission sources.

Although a gradient of pollution has been identified, no corresponding change in tree growth, mortality, or forest decline is evident. However, these forests have been monitored for only a few years (Witter et al., 1989). One trend apparent to researchers is the disruption of nutrient cycles in forests of the Lake States. Increased volumes of pollutants have altered the nutrient cycle in a number of hardwood forests throughout Michigan and Minnesota. In general, temperate forests are limited in many nutrients, particularly nitrogen. The increased level of deposition appears to act as a fertilization for forest ecosystems of the lake states. The ramifications of this have yet to be fully understood, but recent research suggests that the imbalance of nutrients in a forest ecosystem, and not merely the overloading of one, may be responsible for the forest decline and mortality in Europe, California, and the Appalachian Mountains (MacKenzie and El-Ashry, 1988; Ratloff, 1989).

FOREST PRACTICES AND POLICIES

Federal Level

Policies of federal agencies including the U.S. Departments of Interior and Agriculture affect hundreds of thousands of acres of forestland in the United States. A division of the Department of Agriculture, the United States Forest Service (USFS), is the largest manager of federal forestlands. The USFS was established under the concept of multiple uses of the forests and, above all, uses that best benefit the citizens of the country. According to Gifford Pinchot, first chief of the Forest Service, the agency's aim was to strive to attain the greatest good for the greatest number in the long run (Robinson, 1988).

In recent years, portions of the U.S. forest management policy have been heavily criticized. One major topic of concern focuses on timber sales of national forests, particularly below-cost timber sales. Although a more urgent problem in the western United States, this concern exists in the lake states and the Northeast (Repetto, 1988). In each of the seven national forests in the northern lake states, the annual costs of timber sales have exceeded receipts every year from 1979 to 1984. During that period losses totalled $87.6 million (The Wilderness Society, Undated).

The timber industry maintains that the national forests are not supplying their share of raw materials needed in our country and favors increased timber sales. Conservationists contend that prices for national forestland timber are artificially depressed by USFS below cost sales. This practice, they say, discourages management and sale of private commercial forestland by putting the private timber market at a competitive disadvantage. The USFS maintains that harvesting provides additional benefits such as creating needed jobs and enhances wildlife through the creation of diverse habitats (The Wilderness Society, Undated).

Under a new USFS plan, total harvest from the national forests would rise with regional concentration shifting from the Pacific Coast to the Rockies to the eastern seaboard (Adams and Haynes, 1989). Adams and Haynes predict that overall domestic production of wood products will rise. However, between 1995 and 2005 harvests are likely to fall below the current level. The Pacific Coast harvests are expected to be most severely affected, and its harvests as well as jobs will be redistributed to other regions of the country.

However, not all federal forest policy relates to removal of timber. In recent years, considerable emphasis has been placed on setting aside wilderness areas. Under section 6 of Public Law 93-378 amended by Public Law 94-588 (16 USC 1604), each national forest is required to supply the U.S. Forest Service with a strategic management plan. These plans are to be updated every five years. In Michigan, national forest plans have increased the amount of land set aside as primitive, non-motorized management areas. A total of 91,821 acres within three national parks in Michigan have been designated wilderness land (Padley, 1990).

State Level

Generally, state policies may be divided into two major types: *i*) those associated with silvicultural, management, or biological methods of forest practices and *ii*) those concerning long-term economic status of the forests.

Silviculture is the practice of producing and tending trees, forests, and woodlands in an economically and biologically sound manner to suit desired objectives. Silvicultural treatments include pest control, weed control, intermediate harvesting and pruning, among many other techniques. A silvicultural system is a program of treatments for the entire rotation or "lifetime" of the particular stand or forest.

At the state level, most silvicultural forest policies have been concerned primarily with the number of trees to leave after harvesting a certain area, or necessary reforestation. With the passage of the Federal Water Pollution Control Acts of 1972 Amendments (PL 92-500), the language of much of the state forest acts and policies was changed to include aspects of clean water legislation, such as minimizing sedimentation and erosion, and maintaining clean streams. Western states, particularly Washington, Oregon, and California, have state forest policies that are frequently under review and have statutes frequently amended. As of 1982, 16 states have some form of a forestry practices act: Alaska, California, Idaho, Indiana, Maine, Maryland, Massachusetts, Minnesota, Mississippi, Nebraska, Nevada, New Hampshire, New Mexico, Oregon, Virginia, and Washington (Meeks, 1982; Shetron, 1989). However, only six of these (Alabama, Washington, Oregon, California, Idaho, and Nevada) have enacted broad legislation encompassing water quality, recreation, and other non-timber forest resource values (Renew America, 1989).

Comprehensive forest management practices have become important concerns for some interest groups. The Society of American Foresters and the Michigan chapter of the Wildlife Society issued voluntary guidelines in 1987 for proper forest management (Michigan Society American Forestry, 1987). The guidelines define silvicultural techniques and describe the fundamentals of pest management and protection instruction. Oriented toward the private forest manager, the guidelines emphasize long-term and sustained productivity of sites. The guidelines emphasize managing the wildlife resources of the state while maximizing productivity and emphasizing the rights of landowners to manage their land for a variety of objectives.

Forest Resource Management in Michigan

Michigan's Forest Resource Plan established basic forest policy for the state. Among the actions encouraged by the plan is the use of a "key value approach" in applying multiple-use management and in developing comprehensive management plans for each state forest. The key value approach, directs each plan to identify and designate certain areas for specific uses (DNR, 1987). Often, there is some level of conflict between groups who wish to promote timber management, recreation, or wildlife on public land. The basic categories defining forests according to this economic and ecological analysis are: naturalistic, recreational, habitat/vegetation management, and mixed-use zones (Brockway, 1989).

The Forest Resource Plan, implemented in 1982, also drew together the public and private sectors in an effort to aid development of the economy of the state while conserving natural resources. The impetus was diversification of Michigan's economy through expansion of forest products. One outgrowth was the Target Industry Program operated by the Department of Commerce begun by executive action in 1983. It was believed that the Target Industry Program would develop industries in Michigan with potential to contribute significantly to the State's economic diversification. One aspect of the program focuses on both forest products and natural resources (Murray, 1989).

Planning and cooperation between those organizations involved with The Forest Resource Plan and The Target Industry Program have led to the formation of The Lake States Alliance and The Forest Development Fund. An industry development council was also formed to directly address new industrial expansion and interactions. The intent of these organizations is to create a cohesive forest industry group with the aim of insuring economically and environmentally stable uses of Michigan's natural resources.

The Lake States Alliance

The Lake States Forestry Alliance is a cooperative effort between the Michigan, Minnesota, and Wisconsin state forest agencies. In 1987, the governors of these three states pledged their support for cooperative efforts to improve management and promote wise use of the Alliance's forestlands (Shands, 1988). Cooperation between Michigan, Minnesota, and Wisconsin is appropriate because they have a similar natural resource identity which can be managed similarly. For example, their forest compositions, in terms of tree species and age classes, as well as their forest wildlife are generally the same and can be managed as a unit (Shands, 1988).

The emphasis of the Lake States Forestry Alliance is on marketing, regional research, and policy development. The Alliance's objective include: providing jobs and diversifying its economies; increasing markets for timber products; increasing forest-based tourism; and protecting and improving environmental quality (Shands, 1988). In achieving its goals, the Alliance is committed to: actively promoting Lake States forestry initiatives on the federal level; developing national and international markets for the forest based industries in the three states; conducting and funding joint research projects; and promoting public education and understanding of forest protection and management (Hitchcock, 1988; Webster, 1989). One other regional alliance, the Northeastern Forest Alliance, consisting of Maine, New Hampshire, New York, and Vermont, was formed recently.

The Forestry Development Fund

The Forestry Development Fund is a concept that grew out of an analysis of Michigan's economic and fiscal structure by a group of Michigan university economists. Currently, the Forest Management Division of the DNR is evaluating the potential use of the fund to assist in long-term management of Michigan's forest resources (DNR *et al.*, 1987). The intent of this fund is to help finance reforestation, stand improvement, and resource protection on state land through the issuance of bonds. Forest management techniques have traditionally relied on receipts from timber sales on a yearly basis and thus, funding sources were not always reliable (Murray, 1989).

As mentioned earlier, some of the state land harvested annually is not replanted for lack of financial resources. According to the DNR, the outlook for replanting this land is enhanced by the Forestry Development Fund (DNR *et al.*, 1987). Legislation has been introduced to address the fund. House Bill 4688 would create the Michigan Forest Finance Authority and provide for revenue for forest land that has been neglected in the past due to budgetary constraints. House Bill 4688 and a similar bill, Senate Bill 365, are currently in the Senate Natural Resources and Environmental Affairs Committee.

Nonindustrial Private Forest Landowner (NIPFL)

An element of commercial forestland development that has not been given as much attention as it warrants is the private, nonindustrial forests. Fifty-five percent (see Figure 9) of commercial forestland in Michigan is controlled by the private sector (Renew America, 1989). This represents a large resource. However, its fragmented ownership creates problems because it precludes the development of a unified management scheme. At least two-thirds of Michigan's annual harvest is derived from nonindustrial private forest landowners (NIPFLs) (Webster, 1989). However, programs for education, technical assistance for implementing management plans, and cost-sharing programs for private owners are lacking. As a result, approximately 75% of all harvesting on private land in northwestern lower Michigan occurs without regard for regeneration (Niese and Vasievich, 1988). Cooperative efforts in education and tax incentives represent a way of bringing the private non-industrial owner into active forest management (Niese and Vasievich, 1988).

Michigan legislation provides some incentives for NIPFLs and for tree planting in general. As discussed in an earlier section of this report, the Farmland and Open Spaces Act (1974 PA 116) provides tax benefits for growers of Christmas trees. The Commercial Forestry Act (1925 PA 94) provides tax incentives via reduced property tax as long as the property remains accessible to hunting or fishing. However, some people believe the property tax structure needs to be reevaluated, since federal incentives have recently dwindled (Okraszewski, 1989). For example, newer federal tax laws have resulted in a less favorable treatment of NIPFLs who sell timber from their land (Okraszewski, 1989).

As mentioned, federal incentives programs (FIP) for reforestation have been in operation since 1974. FIP is a cost-sharing program between private forest owners and the federal government, primarily aimed at reforestation and the improvement of management practices. Despite these incentives, many acres remain unplanted or neglected. According to Niese and Vasievich (1988), poor quality regeneration occurs on 53% of the upper Great Lake states' private timberland.

A special meeting of the Michigan Forest Products Industry Development Council in 1985 focused on assistance and incentives for private forest owners. They concluded that assistance and incentives for NIPFLs are the cheapest government mechanisms to increase output of timber and other forest values. Other important needs for the NIPFLs include consultation and technical assistance. Ellefson and Risbrudt (1987) recommend that the FIP can be improved by providing better assistance to landowners and by increasing the training for the forestry professionals involved in outreach programs.

A valuable resource for NIPFLs is the Voluntary Forest Management Guidelines for Michigan. This handbook was developed by the Michigan Society of American Foresters in cooperation with Michigan chapter of the Wildlife Society. The guidelines serve as a responsible approach to management for various objectives, foremost conservation and stewardship of forestland in Michigan.

Since Michigan's forest resource is varied spatially and by owner, management practices may differ dramatically. Most large landowners and state and federal governments have woodlands managers to undertake the task of making silviculturally-sound decisions. On the other hand, private landowners do not always have access to managers or consultants. For private landowners, Niese and Vasievich (1988) indicate that there are several ways to increase timber supply and sound management practices. Among these are: direct financial incentives, tax policy changes, technical assistance, regulations, and education. Registration of loggers and consulting foresters and referral of consultants to private foresters would insure legitimate practices (Niese and Vasievich, 1988).

OPTIONS FOR ACTION

The purpose of this document is to provide background into the role of forestry in dealing with global climate changes and atmospheric conditions as well as accommodating increased energy demand in a manner that minimizes damage to the environment. Forestry practices can clearly exert a positive influence, though they are not the sole response. Properly conceived and executed, forest management can make a definite contribution on the federal, state, and local levels.

Investment in solutions for problems that do not have immediate results may be controversial. Moreover, the future severity of climate change itself is unpredictable as is the rate of change. A number of technical options exist for coping with the prospect of global change, all of which involve the reduction of emissions of greenhouse gases. Unlike many of these, tree planting is a low-cost investment that has few if any detrimental side effects. However, forestry practices do not appear capable of providing the whole solution atmospheric changes. Rather, reforestation can best serve as a compliment to other technical control options, or as a means of restoring atmospheric conditions.

In a general way, forestry-related actions can be categorized into four main areas, practices which: 1) promote reforestation efforts; 2) reduce deforestation; 3) improve biomass productivity; and 4) enhance carbon sequestering ability.

Tree planting

According to Schneider (1989b) there are three kinds of responses to the problem of global climate change: a) technical changes; b) adaptation; and c) prevention. The use of tree planting is a combination of these responses.

Tree planting has been shown to be one of the most low-cost and easily implemented options to reduce CO_2 emissions. At the state level, one of the most important and relevant legislative issue pertinent to forests is the establishment, management, and utilization of private forest resources. Tax incentives appear to be useful methods of motivating reforestation and better forest practices.

According to the United States Forest Service, federal and state agencies reforested 3 million acres in 1987. This was accomplished through several USDA programs as well as other state and federally funded programs. For example, the USDA's Conservation Reserve Program was responsible for the planting of 1.6 million acres of trees from 1986 to 1988. Private individuals, companies, and other government reforestation projects may be necessary to achieve the large scale of reforestation necessary to impact atmospheric conditions.

In the temperate regions, several different sources have been proposed as the land base for reforestation (Marland, 1988; Sedjo, 1989). Abandoned cropland that receives adequate precipitation is suitable for planting trees. Other possible plantation sites include the urban forest spaces sought by the Global ReLeaf program. Highway corridors are other possible urban tree planting sites. In Michigan, there are approximately 1,800 miles of four-lane highways that could provide some additional land area for tree planting which could contribute to sequestering carbon. However, liability concerns would need to be addressed as well as other issues such as conflict with road maintenance. Cooperation at many levels would be required.

High biomass-yielding plantations are efficient carbon absorbers. However, these are believed to be more costly and may prove less cost-effective than establishing natural forests, or allowing forests to regenerate. Some rapidly growing plantation forest could be useful, particularly in developing countries where short rotation harvests may be used for fuel wood. Monoculture or single-species plantations, however, create several ecological problems. For example, these can be particularly vulnerable to insect pests, reduce biodiversity, and tend to be aesthetically unpleasing.

Recognizing negative effects of deforestation and fossil-fuel burning emissions, some utility companies are attempting to offset the greenhouse effect by reforestation efforts. Utility companies from Connecticut and Washington have been involved in establishing plantations in tropical countries in response to the building of a new facility (Gurwitt, 1989). A bill has been introduced before the Massachusetts Legislature which would require a developer of a commercial or industrial site to plant one tree for each tree destroyed as a result of the development. The trees would be planted on or near the development site. Obtaining the required certificate of occupancy would be contingent upon completion of the replanting efforts. The bill would also require the developer to plant and maintain, for a period of five years, no less than fifteen hardwood trees for the initial twenty thousand square feet of construction, and one hardwood tree for each ten thousand square feet of additional construction or changes to the development project (Proposed Chapter 40N of the Massachusetts Legislature). Currently, the bill is being amended for adoption (Kleine, 1990).

According to some observers, many federal and state policies have promoted the harvesting of agricultural commodities (including forests), mining, and over depletion of natural resources. However, few federal efforts have focused on reforestation or reclaiming damaged lands (Marland, 1988).

Private Landowner

New trees can mitigate atmospheric pollution and are generally beneficial in many ways. Therefore, planting and reforestation efforts have been promoted at various levels. For private landowners, several options exists. The lack of proper consulting and management assistance for private forest owners is well known. It has been suggested that additional assistance is needed to insure continued tree planting.

Lack of investment capital for forest management practices is a problem for private and public forestlands alike. The state of Michigan is trying to reduce this by advancing the idea of a Forestry Development Fund for state forestlands (see previous section). Practices promoting the development of private forest management can be encouraged in several ways including:

1) Providing direct financial incentives. For example, the state or local government could provide free management plans or free or subsidized tree planting services to promote planting activity.

2) Changing tax policies. Specifically, more favorable federal capital gains treatment of timber may be necessary. Property tax relief could increase planting. The Commercial Forestry Act (1925 PA 94) is the only Michigan law that provides substantial tax relief for Michigan landowners. Some say this may be strengthened or changed so that participants are not required to keep the land open for hunting and fishing (Okraszewski, 1989).

3) Providing technical assistance programs. Instruction in private forest management may provide necessary educational tools for forest owners. Some states have promoted the cooperation of service and extension forestry consultants who work directly with the public disseminating new and useful forest management information.

4) Providing regulations for the nonindustrial private forest landowner. Such measures might include laws requiring forest regeneration, particularly coupled with landowner ethics and stewardship. This approach could provide insurance for healthy forests and ecological diversity.

5) Providing regulations for the registration of foresters and loggers. Although this is not looked upon favorably by the industry, many private forest landowners have witnessed inadequate and poor quality logging practices. In California and Massachusetts, timber harvesters must be licensed and in the latter state, they must pass a written exam.

Financial and tax incentives have traditionally been used to encourage improvements in private forest management practices. These policies promote reforestation, but have little influence on nontimber uses, except indirectly. Therefore, increased forest productivity on private land may be seen as useful in reducing pressure of public lands which often support more diverse habitats.

Urban Forestry

Several organizations have been involved with the reforestation of the landscape (with the goal of sequestering CO_2). These programs, such as Global ReLeaf sponsored by the American Forestry Association are now in the stage of implementation requiring support, particularly at the state and local levels. Since urban trees provide a multitude of benefits, from energy savings and sequestering CO_2 to aesthetic improvements, such endeavors may have few detractors.

In general, urban forestry appears to lack strong support from policy-makers, perhaps because of lack of awareness. The Forest Management Division of the Michigan Department of Natural Resources has a section to address private forest development, but does not have a specific position for an urban forester. It has been suggested that the state employ at least one full-time urban forester. The population of Michigan is arranged such that a majority of the state inhabitants live in urban areas. A state urban forester could help to promote the image of forestry as well as aiding communities in sound urban forest management practices.

More emphasis and support for urban foresters and urban planners could be provided in many areas. Apparently, urban forests need to be revitalized. Tree protection efforts would benefit the urban forest since maintenance and protection demand a great amount of the urban forester's time. Other options include purchasing open or abandoned urban land and reforesting it (Kielbaso *et al.*, 1988).

The Use of Wood Energy

The use of woody biomass as fuel is a way of enhancing wood production, while meeting energy demands and reducing fossil fuel emissions. There is substantial opportunity for wood energy use in Michigan. Promoting the use of wood rather than fossil-fuel sources may curb the emissions of CO_2 into the atmosphere while promoting cultivation of woody crops. However, intensive forest management would be necessary to assure a successful balance.

SUMMARY

New forests are generally more productive forests, so reforestation and planting programs have been widely encouraged. In addition, practices that improve the harvesting of firewood and removal of dead, cull, or undesirable species have also been emphasized. Such activities help in-site preparation for better plantations or forests, in addition to promoting wood as fuel. Both these activities could help limit the amount of atmospheric CO_2.

Forest practices certainly have a significant role in stabilizing increased CO_2 in the atmosphere, but these do not represent the entire answer. New plantations of trees may help offset increasing concentrations of CO_2 by absorbing and sequestering carbon, but reforesting to account for all the CO_2 emissions by a single country does not appear feasible (see Figures 7a-7c). Marland (1988) indicates that the scale of planting to compensate for CO_2 emissions would be equivalent to doubling the net annual yield of all the world's closed forests. Sedjo (1989) indicates that while planting as such is feasible, the cost would be of the same magnitude as the U.S. Defense budget.

If applied with other changes (such as limiting our current industrial and agricultural CO_2 emissions and altering our social behavior), tree planting can be a useful tool. Tree planting is attractive because it is relatively low-cost, it involves no new technology, may be undertaken immediately, and the benefits are manifold. Even if a tree has an undesirable growth form or appearance, it still serves some benefit. Actions to support programs to grow trees are almost universally encouraged. Most actions to support tree planting and management appear very sensible. An example may be to plant trees (possibly energy crops) on abandoned farmland. However, a solution as such requires not merely tree planting, but proper management for forests, particularly increased yields in temperate forests.

Other forest-related policies have direct ramifications for global climate change. Globally, deforestation may need to be limited, lest we lose a significant component of the earth's CO_2-sequestering vegetation. Deforestation also contributes in part to the growing pool of atmospheric CO_2, particularly when forests are cut and burned.

Research is needed to clarify all aspects of the contribution of forests to the environment and energy. Specifically, research to pursue or develop relatively insect-free, pollution-resistant trees that grow fast and sequester carbon for urban areas is needed. Climate models alone are complex, but even systems that we ostensibly comprehend, like trees, are confounding when assessing atmospheric interactions. For example, studies examining interactions of trees and the atmosphere are too often based on generalized models and are not specific to individual tree species.

Options to reduce the impact of atmospheric or climate change and to enhance forestry are generally available. They are, moreover, attractive since they are relatively inexpensive and often satisfy a number of social values and needs. Forest management alternatives are diverse and may be applied on a broad scale, or very selectively. However, the pursuit of these options is not simply a natural resources question. Deciding where to plant trees, what kinds to plant and the quantity will involve a number of political, economic, and environmental considerations.

REFERENCES

Abelson, P. "Editorial." Science. Vol. 241, p. 1569. September 23, 1988.

Adams, D.M. and R. W. Haynes. "Changing Timber Policies may bring other Changes." Journal of Forestry. Vol. 87, pp. 24-31. 1989.

Akbari, H., J. Huang, P. Martien, L. Rainer, A. Rosenfeld, and H. Taka. "The Impact of Summer Heat Islands on Cooling Energy Consumption and CO_2 Emissions." Volume 5. Proceedings of the 1988 American Council for an Energy Efficient Economy. Washington, D.C. 1988.

Albert, D.A., S.R. Denton, an B.V. Barnes. Regional Landscape Ecosystems of Michigan. School of Natural Resources. The University of Michigan. 1986.

Bazzaz, F.A., K. Garbutt, and W.E. Williams. The Effect of Elevated Atmospheric CO_2 on Plant Communities. U.S. Department of Energy. DOE/EV/04329-5. July 1985.

Bernatzky, A. Tree Ecology and Preservation. Elsevier. 1978.

Bertsch, R. Forest Management Division. Michigan Department of Natural Resources. Personal Communication. 1989.

Booth, W. "Johnny Appleseed and the Greenhouse." Science. Vol. 241, pp. 19-20. 1988.

Booth, W. "New Thinking on Old Growth." Science. Vol 244, pp. 141-143. 1989.

Botkin, D.F. and R.A. Nisbet. "Projecting the Effects of Climate Change on biological Diversity in Forests." in press: Consequences of the Greenhouse Effect for Biological Diversity. ed. R. Peters. Yale University Press. October 31, 1989.

Bowles, Dennis. Forestry Supervisor. Flint Park and Forestry Division. Personal Communication. January 25, 1990.

Brockway, D. Forest Management Division. Michigan Department of Natural Resources. Personal Communication. July 7, 1989.

Brown, S. and A.E. Lugo. Biotropica. Vol. 14, p. 161. 1982.

Brown, S., A.E. Lugo, and J. Chapman. "Biomass of Tropical Tree Plantations and its Implications for the Global Carbon Budget." Canadian Journal of Forest Research. Vol. 16, pp. 390-394. 1986.

Chameides, W.L., R.W. Lindsay, J. Richardson, and C.S. Kiang. "The Role of Biogenic Hydrocarbons in Urban Photochemical Smog: Atlanta as a Case Study." Science. Vol. 241, pp. 1473-1475. September 16, 1988.

Chappelle, D.E. and H.H. Webster. "Forest Resources as Regional Economic Assets in the Lake States." in: The Lake States Forests, A Resources Renaissance. Editor: Wm. E. Shands. pp. 36-46. 1988.

Cicerone, R. "Global Warming, Acid Rain, and Ozone Depletion." in: The Challenge of Global Warming. Editor: D.E. Abrahamson. Island Press: Washington, D.C. pp. 231-238. 1989.

Cool, R.A. Registered Forester, Metropolitan Forestry Consultants. Personal Communication. July 10, 1989.

Dahlberg, J. Woodlands Manager. Champion International. Personal Communication. August 18, 1989.

Davis, M.B. "Incites from Paleoecology on Global Change." Bulletin of Ecological Society of America. Vol. 70, No. 4, pp. 222-228. December 1989.

Detwiler, R.P. "Land Use Change and the Global Carbon Cycle: the Role of Tropical Soils." Biogeochemistry. Vol 2, pp. 67-93. 1986.

Detwiler, R.P. and C.A.S. Hall. "Tropical Forests and the Global Carbon Cycle." Science. Vol. 239, pp. 42-47. 1988.

Dickmann, D.I., K.S. Pregitzer, and P.V. Nguyen. Net Assimilation and Photosynthate Allocation of Populus Clones Grown under Short Rotation Intensive Culture: Physiological and Genetic Responses Regulating Yield. Annual Progress Report. Short Rotation Woody Crops Program. United States Department of Energy. 1989.

DNR (Forest Management Division), Department of Treasury, and Cabinet Council for Jobs and Economic Development. Forest Development Fund: An Investment Oriented Funding Arrangement for Michigan's State Forest System. November 1987.

Downs, Ethan. Detroit Park Development Coordinator. Personal Communication. January 25, 1990.

Ebenreck,S. "Measuring the Value of Trees." American Forests. July/August 1988.

Ellefson, P.V. and C.D. Risbrudt. "Economic Evaluation of a Federal Natural Resources Program." Evaluation Review. Vol. 11, pp. 660-669. 1987.

Evans, R.C., D.T. Tingey, and M.L. Gumpertz. "Interspecific Variation in Terpenoid Emissions from Engelmann and Sitka Spruce Seedlings." Forest Science. Vol. 31, pp. 132-142. 1985.

Frankena, F. "Public Controversies Reveal Major Social Changes, Wood-Fired Electric Power Plants." Journal of Forestry. April 1989.

Garrett, L.D. "Forests and Woodlands—Stored Energy for Our Use." in: Cutting Energy Costs. The 1980 Yearbook of Agriculture. ed. J. Hayes. U.S. Department of Agriculture. Washington, D.C. 1980.

Global ReLeaf. Brochure. American Forestry Association. Washington, D.C. Undated.

Graedel, T.E. and P.J. Crutzen. "The Changing Atmosphere." Scientific American. pp. 58-68. September 1989.

Grainger, A. "Estimating Areas of Degraded Tropical Lands Requiring Replenishment of Forest Cover." International Tree Crops Journal. Vol. 5, pp. 1-2. 1988.

Gurwitt, R. "Connecticut wants a Share of Power Company's Trees." Governing the States and Localities. February 1989.

Hansen, J.E. "Irrigating Short Rotation Intensive Culture Hybrid Poplars." Biomass. Vol. 16, pp. 237-250. 1988.

Hansen, J.E. "The Greenhouse Effect: Impacts on Current Global Temperature and Regional Heat Waves." in: The Challenge of Global Warming. Editor: D.E. Abrahamson. Island Press: Washington, D.C. pp. 35-44. 1989.

Hanson, K. "Are Atmospheric "Greenhouse" Effects Apparent in the Climate Record of the Contiguous US (1895-1987)?" Geophysical Research Letters. Vol. 16, pp. 49-52. 1989.

Hartl, D.L. Principles of Population Genetics. Sinauer Associates. 1989.

Hitchcock, R.B. "The Minnesota View." in: The Lake States Forests. W.E. Shands, ed. The Lakes States Forestry Alliance. pp. 125-128. 1988.

Houghton, R.A., J.E. Hobbie, J.M. Melillo, B. Moore, B.J. Peterson, G.R. Shaver, and G.M. Woodwell. "Changes in the Carbon Content of Terrestrial Biota and Soils Between 1860 and 1980: a Net Release of CO_2 to the Atmosphere." Ecological Monographs. Vol. 53, pp. 235-262. 1983.

Houghton, R.A., W.H. Schlesinger, S. Brown, and J.F. Richards. "Carbon Dioxide Exchange Between the Atmosphere and Terrestrial Ecosystems." in: Atmospheric Carbon Dioxide and the Global Carbon Cycle. Chapter 6. U.S. Department of Energy. DOE/ER-0239. 1985.

Houghton, R.A. and G.M. Woodwell. "Global Climatic Change." Scientific American. pp. 36-44. April 1989.

James, L.M., S.E. Heinen, D.I. Olson, and D.E. Chappelle. Timber Products Economy of Michigan. Michigan State University Agricultural Experiment Station. 1982.

Janzen, D.H. "Tropical Ecological and Biocultural Restoration." Science. pp. 243-244. January 15, 1988.

Kielbaso, J.J., B.S. Beauchamp, K.F. Larison, and C.J. Randall. Trends in Urban Forestry Management. Baseline Data Report. Vol. 20, No. 1. Washington, D.C. International City Management Association. January/February 1988.

Kielbaso, J.J. Professor of Urban Forestry. Department of Forestry. Michigan State University. Personal Communication. August 8, 1989.

Kleine, E. Executive Office of Environmental Affairs. Boston, Massachusetts. Personal Communication. January 11, 1990.

Kramer, P.J. and T.T. Kozlowski. The Physiology of Woody Plants. Academic Press. 1979.

Kramer P.J. and N. Sionit. "Effects of Increasing Carbon Dioxide Concentration of the Physiology and Growth of Forest Trees." in: The Greenhouse Effect, Climate Change, and U.S. Forests. eds. W.E. Shands and J.S. Hoffman. The Conservation Foundation. Washington, D.C. 1987.

Larcher, W. Physiological Plant Ecology. Springer-Verlag. 1980.

Larson, Jim. Assistant Superintendent of Public Works. Escanaba, Michigan. Personal Communication. January 25, 1990.

MacKenzie, J.J. and M.T. El-Ashry. Ill Winds: Airborne Pollution's Toll on Trees and Crops. World Resources Institute. September 1988.

Machado, S. and R. Piltz. Reducing the Rate of Global Warming, the State's Role. Renew America. Washington, D.C. November 1988.

Marland, G. The Prospect of Solving the CO_2 Problem Through Global Reforestation. U.S. Department of Energy. Office of Energy Research. DOE/NBB-0082. 1988.

Marty, R.J. "Cost Effectiveness of Educational and Technical Assistance." A Focused Discussion of Assistance and Incentives for Private Forest Owners. Proceedings of a Special Meeting of The Michigan Forest Products Industry Development Council. Lansing, Michigan. July 11, 1985.

Meeks, G. A Legislator's Guide to Forest Resource Management. National Conference of State Legislatures. Denver, Colorado. 1982.

Meier, A. "Using Water to Save Energy." Home Energy. pp. 23-27 July/August 1989.

MERRA, Toward a Unified Michigan Energy Policy. Michigan Energy and Resource Research Association. Detroit, Michigan. January 1980.

Michaels, P.J. "The Greenhouse Effect: Chicken Little and Our Response to 'Global Warming'." Journal of Forestry. Vol. 87, pp. 35-39. 1989.

Michigan Department of Commerce. Michigan Forest Products Industry, On the Cutting Edge. Undated.

Michigan Department of Commerce. Manufacturing Services Bureau. Forest Products Opportunities in Michigan. September 1986.

Michigan Society American Forestry. Voluntary Forest Management Guidelines for Michigan. Prepared in Cooperation with the Michigan Chapter of The Wilderness Society. 1987.

Mintzer, I.M. A Matter of Degrees: The Potential for Controlling the Greenhouse Effect. World Resources Institute. 1987.

Moll, G. "The State of Our City Forests." American Forests. May/June, 1987.

Mooney, H.A., P.M. Vitousek, and P.A. Matson. "Exchange of Materials Between Terrestrial Ecosystems and the Atmosphere." Science. Vol. 238, pp. 926-932. 1987.

Murray, R.L. New Resources for Funding Extensive Forest Management. North Hardwood Research Council and Northeast Forest Planners Association. 1989.

Nichols, D. Wood Energy Demonstration Project. Department of Forestry. Michigan State University. Personal Communication. January 23, 1990.

Niese, J.N. and J.M. Vasievich. Long-Term Timber Supplies: Some Keys to Future Productivity. Presented at the Minnesota's Timber Supply Perspectives and Analysis Conference. Grand Rapids, Minnesota. September 21-22, 1988.

Okraszewski, J. Woodlands Manager. Mead Corporation. Personal Communication. August 17, 1989.

Paasche. Grand Rapids Urban Forestry Management. Personal Communication. January 25, 1990.

Padley, E. Hiawatha National Forest. U.S. Forest Service. Personal Communication. January 22, 1990.

Parker, J. Uses of Landscaping for Energy Conservation. Department of Physical Sciences. Florida International University. Miami, Florida. 1981.

Penham, C. "Green Protection." EPA Journal. February 1978.

Pedersen, L. and D.E. Chappelle. "The Economic Importance of Upper Lake States Forest Resources: Modeling Lake States Forest Products and Service." in: The Lake States Forests. W.E. Shands, ed. The Lakes States Forestry Alliance. pp. 167-194. 1988.

Postel, S. "Global View of a Tropical Disaster." American Forests. American Forestry Association. November/December 1988.

Potter-Witter, K. and B. Haraty. Michigan Forest Economy: The Facts. Revised Version. University Publications. Michigan State University. July 1988.

Raloff, J. "Where Acids Reign." Science News. Vol. 136(4), pp. 56-58. July 1989.

Rasmussen R.A. and F.W. Went. "Volatile Organic Matter of Plant Origin in the Atmosphere." Proceedings of the National Academy of Sciences. Vol. 53, pp. 215-220. 1965.

Reichle, D.E. "Analysis of Temperate Forest Ecosystems." in: Ecological Studies Volume 2. Springer-Verlag. 1970.

Renew America. The State of the States 1989. Washington, D.C. February 1989.

Repetto, R. "Subsidized Timber Sales from National Forest Lands in the United States." in: Public

Policies and the Misuse of Forest Resources. eds. R. Repetto and M. Gillis. World Resources Institute. pp. 353-379. 1988.

Reuschel, T.M. Forest Management Division. Michigan Department of Natural Resources. Personal Communication. 1989.

Revelle, Roger. "Carbon Dioxide and World Climate." Scientific American. Volume 247. August 1982.

Rind, David. "A Character Sketch of Greenhouse." EPA Journal. Volume 15, Number 1. January/ February 1989.

Roberts, L. "How Fast Can Trees Migrate?" Science. Vol. 243, pp. 735-737. 1989.

Robinette, G. "Landscape Planning for Energy Conservation." Environmental Design Press. American Society of Landscape Architecture Foundation. 1977.

Robinson, G. The Forest and The Trees. Island Press. Washington, D.C. 1988.

Roshetko, J. Extension Forester. Michigan State University. Personal Communication. 1989.

Rosner, M. Buskirk Lumber Co. Personal Communication. 1989.

Royer, J.P. and R.J. Moulton. "Reforestation Incentives: Tax Incentives and Cost Sharing in the South." Journal of Forestry. pp. 45-47. August 1987.

Sampson, R.N. "ReLeaf for Global Warming." American Forests. American Forestry Association. pp. 9-14. November/December 1988.

Schneider, S.H. "The Greenhouse Effect: Science and Policy." Science. Vol. 243, pp. 771 - 781. February 10, 1989a.

Schneider, S.H. "The Changing Climate." Scientific American. pp. 70-79. September 1989b.

Sedjo, R.A. "Forests to Offset the Greenhouse Effect." Journal of Forestry. Vol. 87, pp. 12-15. July 1989.

Seidel, S. and D. Keyes. Can We Delay a Greenhouse Warming? Strategic Studies Staff. Office of Policy Analysis. Office of Policy and Resources Management. Washington, D.C. 1983.

Shands, W.E. "Conference Overview." in: The Lake States Forests. W.E. Shands, ed. The Lakes States Forestry Alliance. pp. 1-10. 1988.

Shetron, S. Professor of Forestry. School of Forestry and Wood Products. Michigan Technological University. Personal Communication. December 14, 1989.

Smith, J.B. and D.A. Tirpak. The Potential Effects of Global Climate Change on the United States. Draft Report to Congress. U.S. Environmental Protection Agency. 1988.

Smith, W.B. and J.T. Hahn. Michigan's Forest Statistics, 1987: An Inventory Update. General Technical Report NC-112. North Central Forest Experiment Station. Forest Service. U.S. Department of Agriculture. 1986.

Solomon, A.M. "Transient Response of Forests to CO_2-Induced Climate Change: Simulation Modeling Experiments in Eastern North America." Oecologia. Vol. 68, pp. 567-579. 1986.

Solomon, A.M., J.R. Trabalka, D.E. Reichle, and L.D. Voorhees. "The Global Cycle of Carbon." in: Atmospheric Carbon Dioxide and the Global Carbon Cycle. Chapter 1. United States Department of Energy. DOE/ER-0239. 1985.

Solomon, A.M. and D.C. West. "Potential Responses of Forests to CO_2-Induced Climate Change." in: Characterization of Information Requirements for Studies of CO_2 Effects. Water Resources, Agriculture, Fisheries, Forests, and Human Health. U.S. Department of Energy. DOE/ER-0236. Washington, D.C. pp. 145-169. 1985.

Stearns, F. "The Changing Forests of the Lake States." in: The Lake States Forests. W.E. Shands, ed. The Lakes States Forestry Alliance. pp. 25 - 35. 1988.

Strain, B.R. "Physiological and Ecological Controls on Carbon Sequestering in Terrestrial Ecosystems." Biogeochemistry. 1:219-232. 1985.

The Wilderness Society. Forests of the Future? Washington, D.C. Undated.

Tingey D.T. and W.F. Burns. "Hydrocarbon Emissions From Vegetation." in: Effects of Air Pollutants on Mediterranean and Temperate Forest Ecosystems. USDA Forest Service General Technical Report PSW-43. 1980.

USDA. National Resources Inventory. Soil Conservation Service. 1982a.

USDA. An Analysis of the Timber Situation in the U.S. 1952-2030. United States Department of Agriculture Forest Service. Forest Resource Report No. 23. 1982b.

USDA. Forests for America's Future: A Research Program for the 1990s. United States Department of Agriculture Forest Service. 1989.

Vincent, J.R. Forestry Economist. Department of Forestry. Michigan State University. Personal Communication. 1989.

Vitousek, P.M., P.R. Ehrlich, A.H. Ehrlich, P.A. Matson. "Human Appropriation of the Products of Photosynthesis." BioScience. Vol. 36, pp. 368-373. June 1986.

Webster. H. Forestry Management Division. Michigan Department of Natural Resources. Personal Communication. 1989.

Weide, H. "Untersuchungen zur Assimilation, Atmung und Transpiration von Sequoia Glyptostroboides." Arch. Forstwes. Vol 11, pp. 1209-1229. 1962.

Whitney, G.G. "An Ecological History of the Great Lakes Forest of Michigan." Journal of Ecology. Vol 75, pp. 667-684. 1987.

Witter, J., G. Mroz, and K. Pregitzer. Michigan Gradient Case History Study for the NAPAP Assessment Plan. Report to the Environmental Protection Agency and the U.S.D.A. Forest Service. 1989.

Wright, L.L., J.H. Cushman, and P.A. Layton. "Expanding the Market by Improving the Resource." Biologue. Vol. 6(3), pp. 12-19. June/ July/August 1989.

Zimmerman, P.R., R.B. Chatfield, J. Fishman, P.J. Crutzen, and P.L. Hanst. "Estimates on the Production of CO and H_2 from the Oxidation of Hydrocarbon Emissions from Vegetation." Geophysical Research Letters. Vol. 5, No. 8, pp. 679-681. August 1978.

"And the Lord God made all kinds of trees grow out of the ground—trees that were pleasing to the eye and good for food."

Genesis 2:9

"No living man will see again the virgin pineries of the Lake States, or the flatwoods of the coastal plain, or the giant hardwoods; of these, samples of a few acres each will have to suffice."

Aldo Leopold, *A Sand County Almanac*

"Every farm woodland, in addition to yielding lumber, fuel, and posts, should provide its owner a liberal education."

Aldo Leopold, *A Sand County Almanac*

"When the brothers were cutting wood, he would forbid them to cut down the whole tree so that it might grow up again. He also ordered the gardeners not to dig up the edges of the gardens so that wild flowers and green grasses could grow and glorify the Father of all things . . . He picked up worms so they would not be trampled on and had honey and wine set out for the bees in the winter season. He called by the name of brother all animals . . ."

said of St. Francis by his biographer Thomas Celano

"The days have ended when the forest may be viewed only as trees and trees viewed only as timber. The soil and water, the grasses and the shrubs, the fish and the wildlife, and the beauty that is the forest must become integral parts of resource managers' thinking and actions."

Hubert Humphrey, principal sponsor of the National Forest Management Act